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(54) **SYSTEMS AND METHODS FOR THREAT IDENTIFICATION AND REMEDIATION**

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(52) **U.S. Cl.**
USPC **726/25**

(57) **ABSTRACT**

Instrumented networks and platforms having target subjects (devices, transactions, services, users, organizations) are disclosed. A security orchestration service generates runtime operational integrity profiles representing and identifying a level of threat or contextual trustworthiness, at near real time, of subjects and applications on the instrumented target platform. Systems and methods for threat identification and remediation for computing platforms based upon reconnaissance-based intelligence correlation and network/application monitoring are disclosed. In an embodiment, a method provides runtime operational integrity of a system by receiving: a dynamic context including endpoint events; and network endpoint assessments. The method generates temporal events based on the network endpoint assessments and correlates the endpoint events and temporal events before generating an integrity profile for the system. In another embodiment, flow level remediation is provided to isolate infected or compromised systems from a computing network fabric using a network trust agent, an endpoint trust agent, and a trust orchestrator.

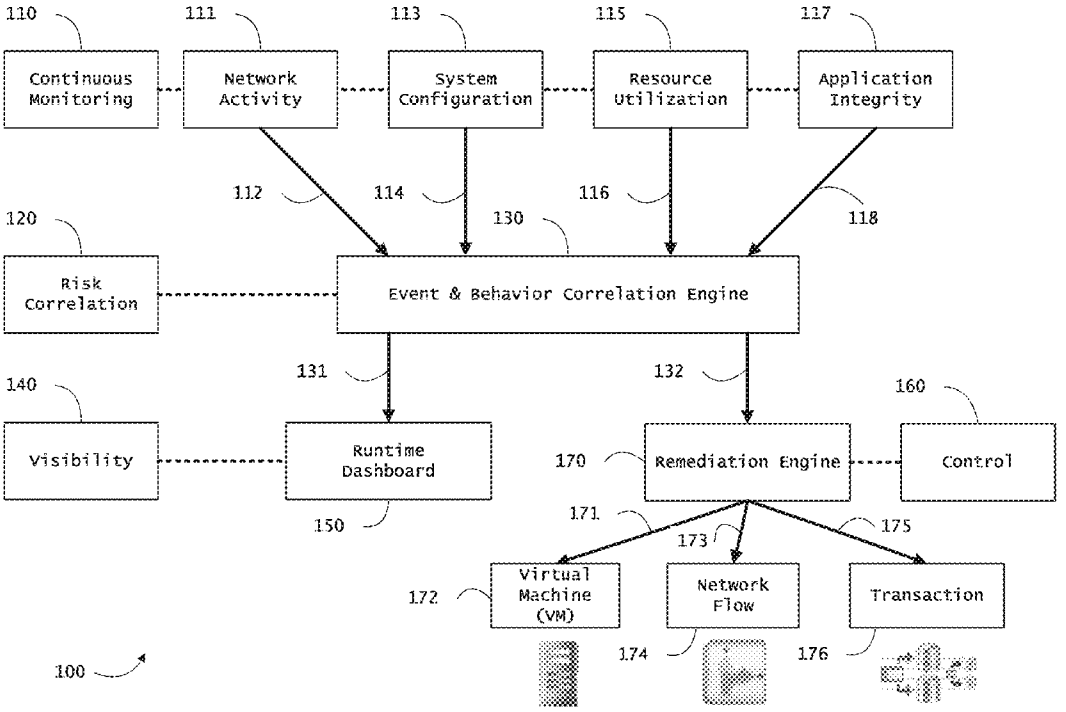


FIG. 1

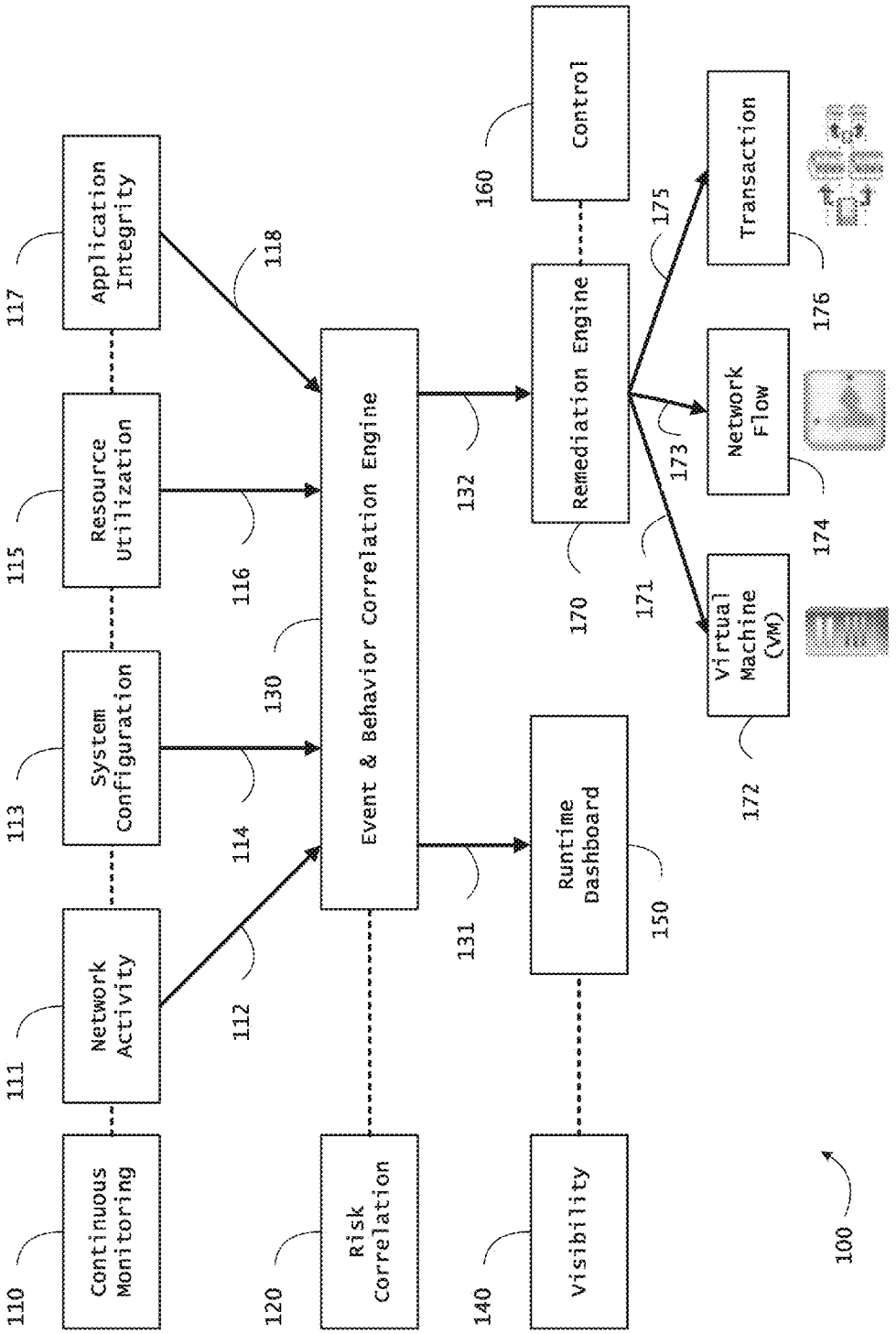

Continuous Monitoring
110
Network Activity
111
System Configuration
113
Resource Utilization
115
Application Integrity
117
112
114
116
118
Risk Correlation
120
Event & Behavior Correlation Engine
130
131
132
Visibility
140
Runtime Dashboard
150
Remediation Engine
170
Control
160
171
173
175
Virtual Machine (VM)
172
Network Flow
174
Transaction
176
100

FIG. 2

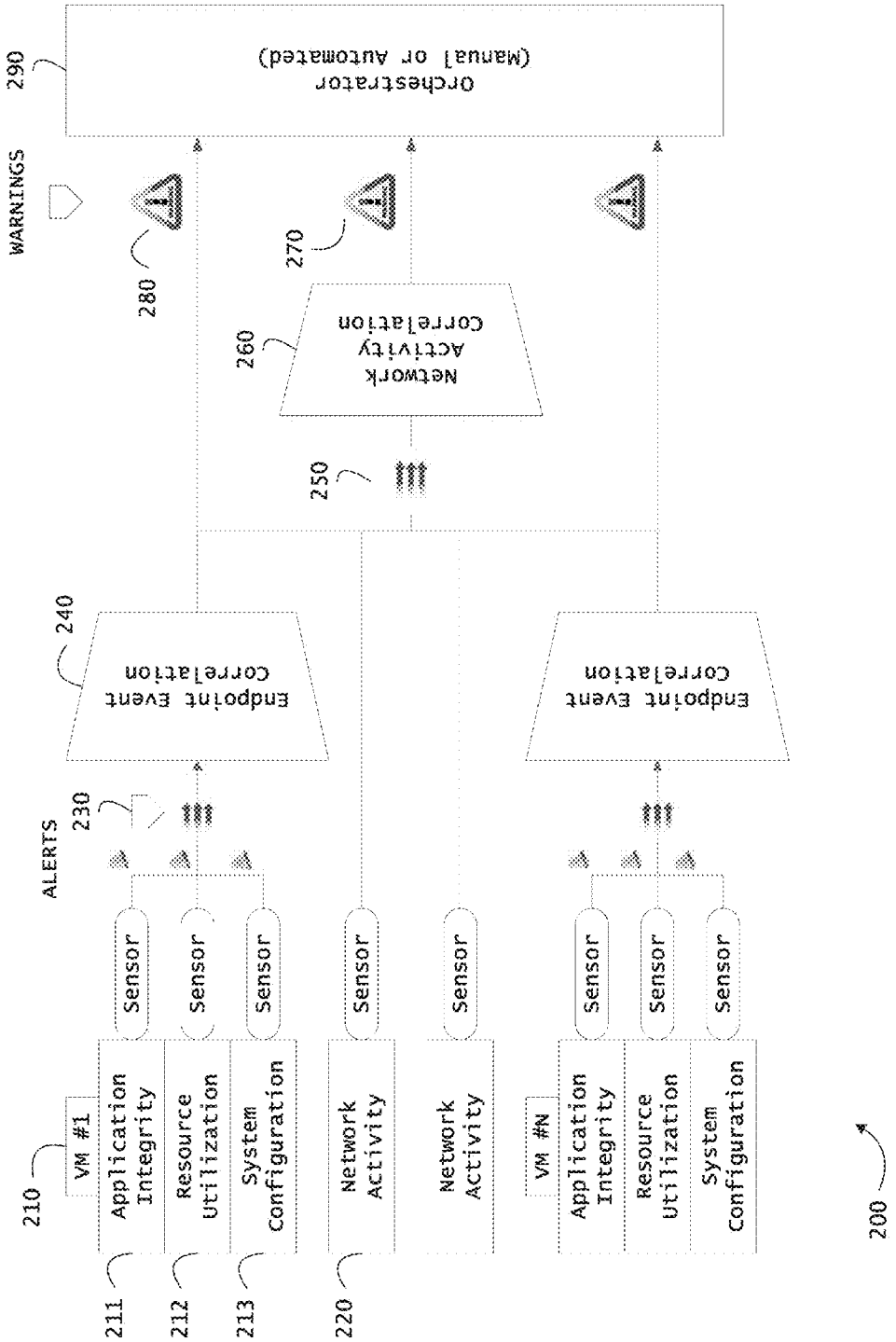

290
Orchestrator
(Manual or Automated)
WARNINGS
280
270
260
Network
Activity
Correlation
250
240
Endpoint Event
Correlation
Endpoint Event
Correlation
ALERTS
230
Sensor
Sensor
Sensor
Sensor
Sensor
Sensor
Sensor
Sensor
210
VM #1
Application
Integrity
Resource
Utilization
System
Configuration
Network
Activity
Network
Activity
VM #N
Application
Integrity
Resource
Utilization
System
Configuration
211
212
213
220
200

FIG. 3A

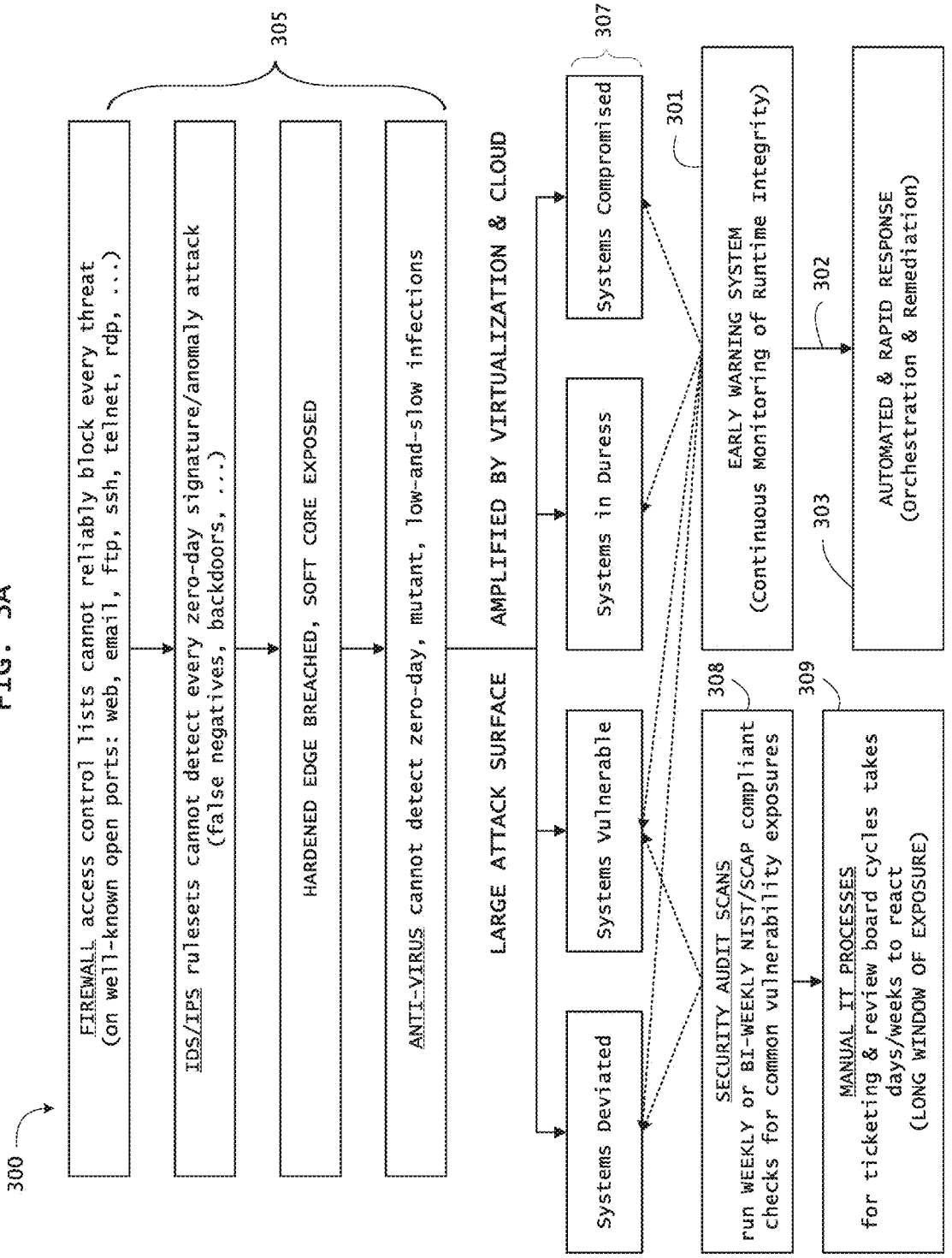

300
305
FIREWALL access control lists cannot reliably block every threat
(on well-known open ports: web, email, ftp, ssh, telnet, rdp, ...)
IDS/IPS rulesets cannot detect every zero-day signature/anomaly attack
(false negatives, backdoors, ...)
HARDENED EDGE BREACHED, SOFT CORE EXPOSED
ANTI-VIRUS cannot detect zero-day, mutant, low-and-slow infections
LARGE ATTACK SURFACE
AMPLIFIED BY VIRTUALIZATION & CLOUD
Systems Deviated
Systems Vulnerable
Systems in Duress
Systems Compromised
307
301
EARLY WARNING SYSTEM
(Continuous Monitoring of Runtime Integrity)
302
303
AUTOMATED & RAPID RESPONSE
(Orchestration & Remediation)
308
SECURITY AUDIT SCANS
run WEEKLY or BI-WEEKLY NIST/SCAP compliant
checks for common vulnerability exposures
309
MANUAL IT PROCESSES
for ticketing & review board cycles takes
days/weeks to react
(LONG WINDOW OF EXPOSURE)

FIG. 3B

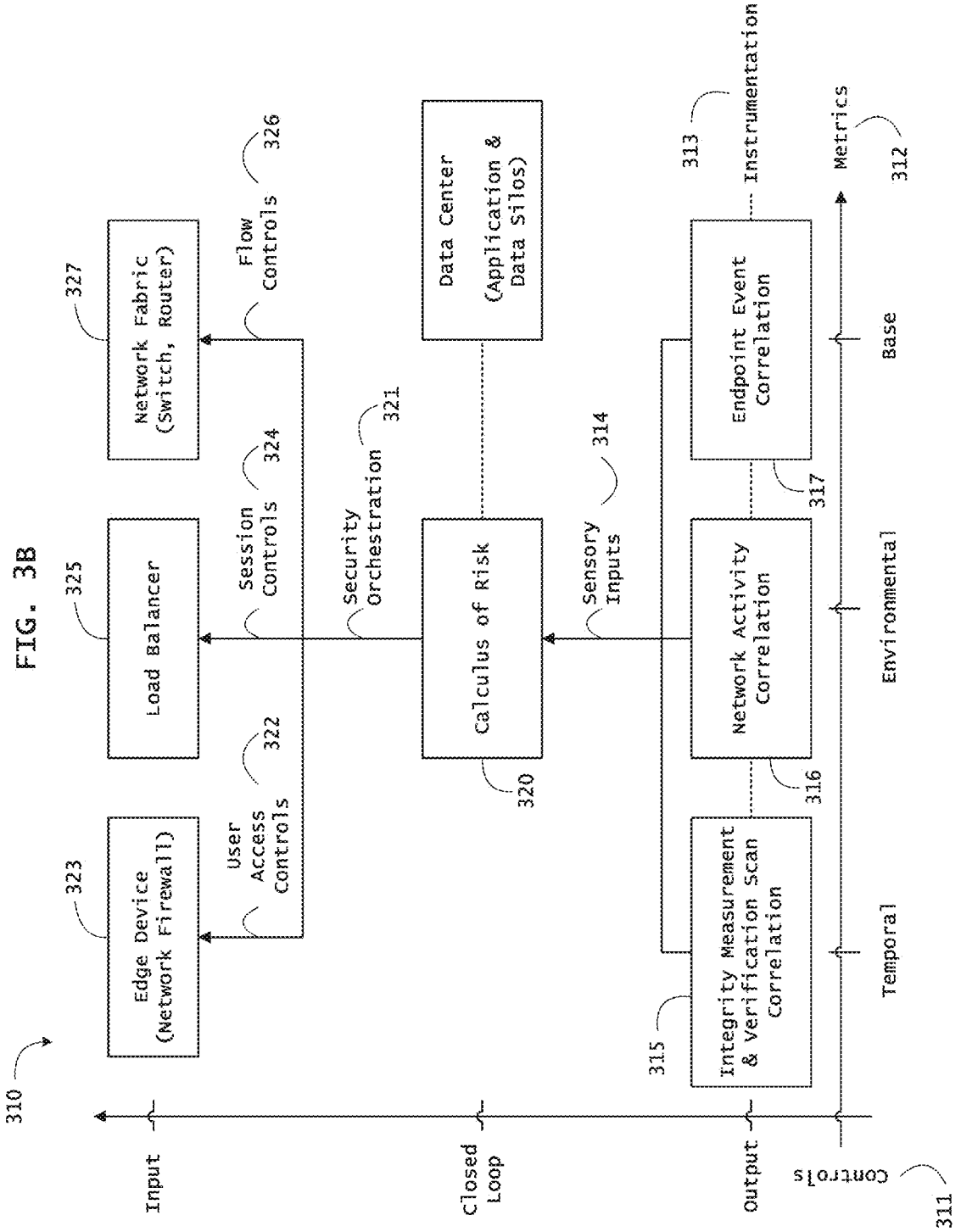

310
Input
Closed Loop
Output
Controls
311
Edge Device (Network Firewall)
323
Load Balancer
325
Network Fabric (Switch, Router)
327
User Access Controls
322
Session Controls
324
Flow Controls
326
Security Orchestration
321
Calculus of Risk
320
Data Center (Application & Data Silos)
Sensory Inputs
314
Integrity Measurement & Verification Scan Correlation
315
Network Activity Correlation
316
Endpoint Event Correlation
317
Instrumentation
313
Temporal
Environmental
Base
Metrics
312

FIG. 4

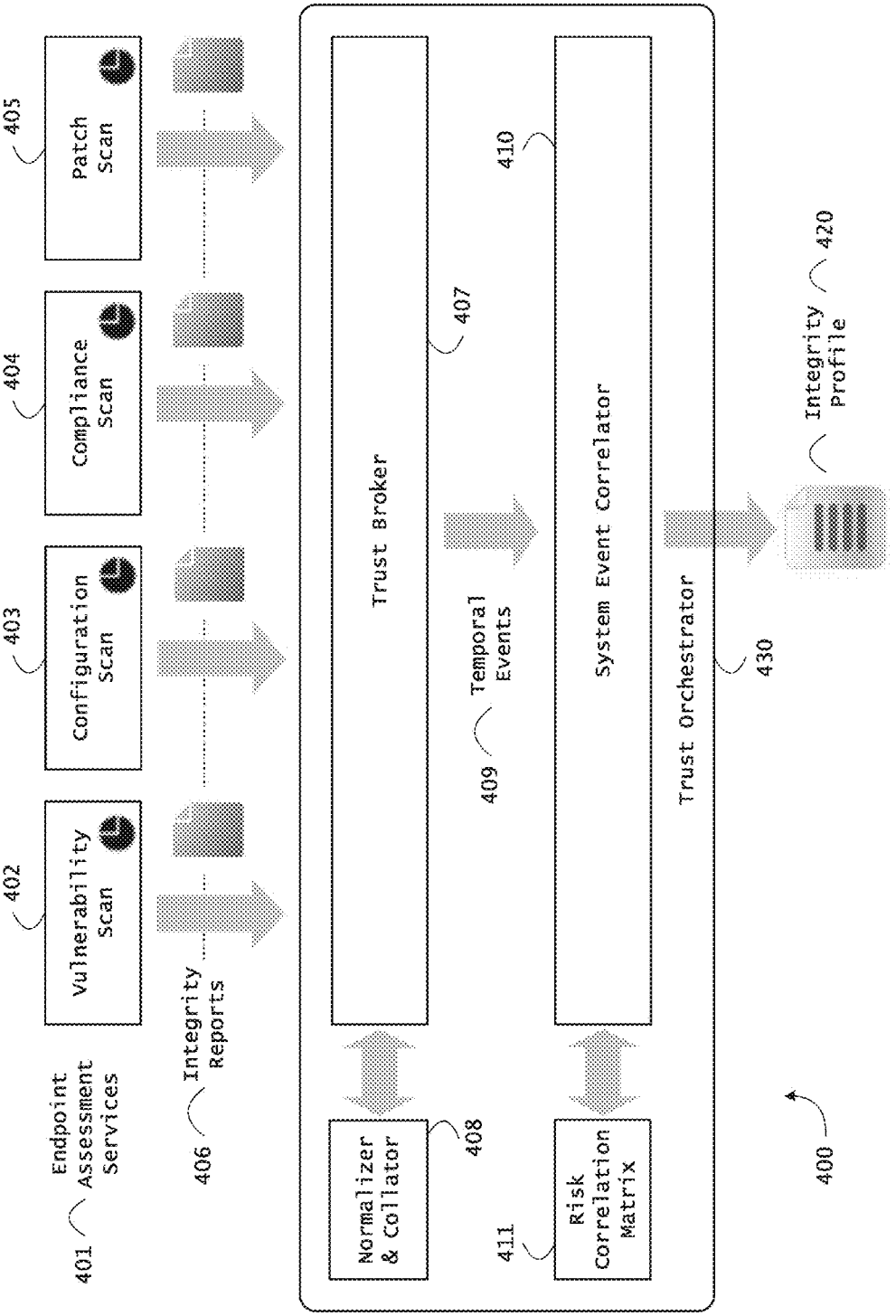

Endpoint Assessment Services
401
Vulnerability Scan
402
Configuration Scan
403
Compliance Scan
404
Patch Scan
405
Integrity Reports
406
Normalizer & Collator
408
Risk Correlation Matrix
411
Trust Broker
407
Temporal Events
409
System Event Correlator
410
Trust Orchestrator
430
Integrity Profile
420
400

FIG. 5

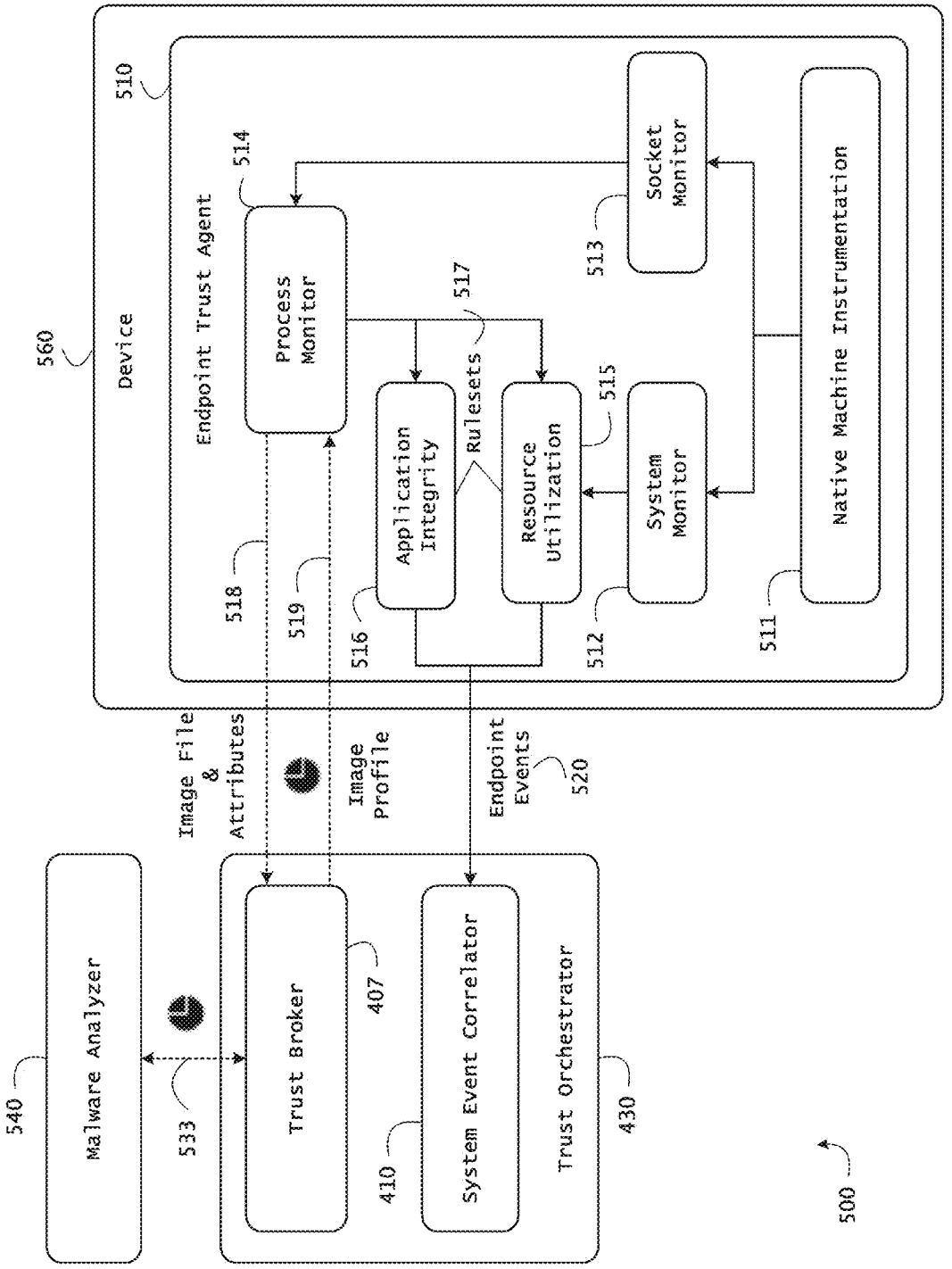

560
Device
510
Endpoint Trust Agent
514
Process Monitor
517
Rulesets
Application Integrity
Resource Utilization
515
Socket Monitor
513
System Monitor
512
Native Machine Instrumentation
511
518
519
516
Image File & Attributes
Image Profile
Endpoint Events
520
540
Malware Analyzer
533
Trust Broker
407
System Event Correlator
410
Trust Orchestrator
430
500

FIG. 6

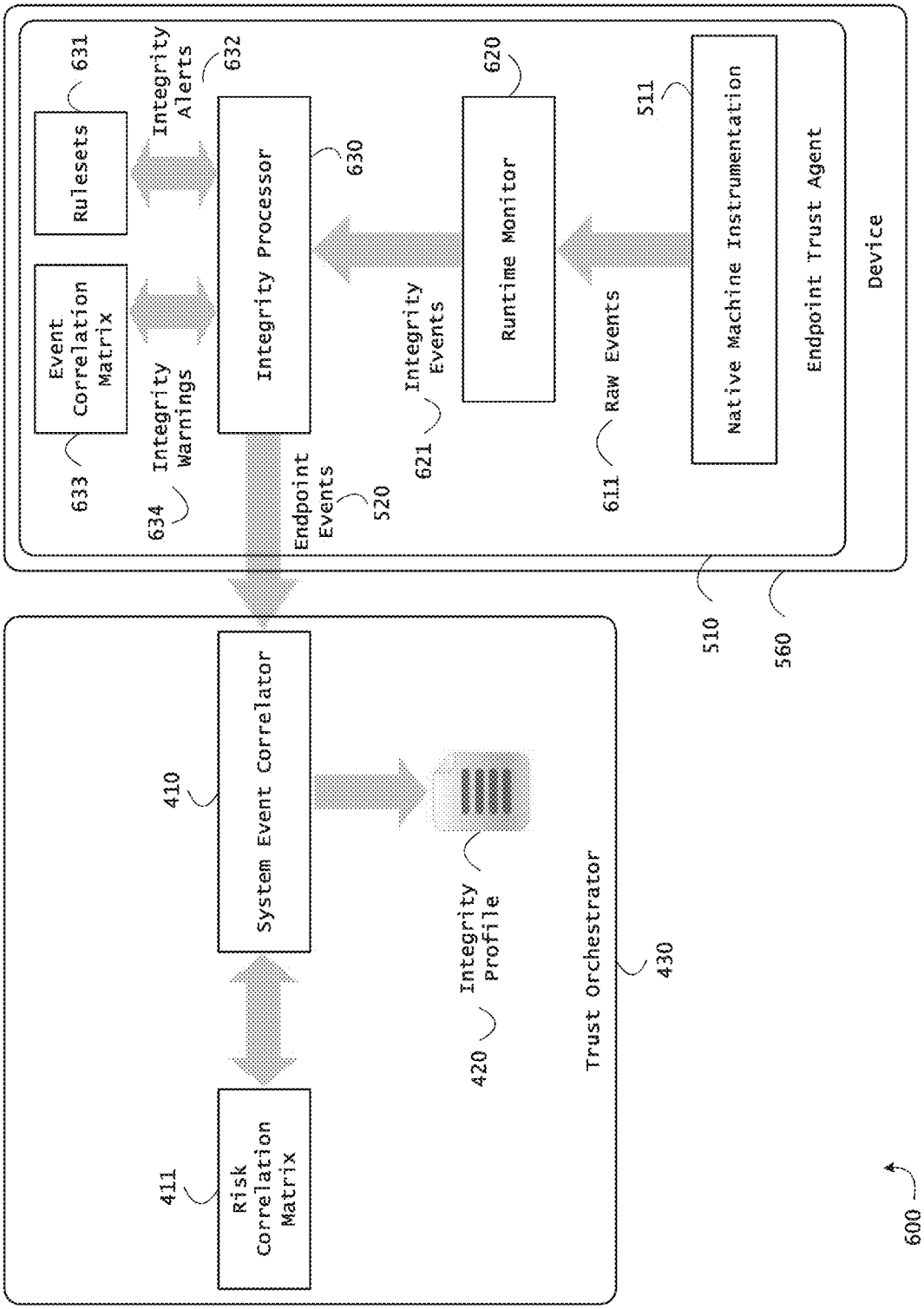

Rulesets
631
Event Correlation Matrix
633
Integrity Alerts
632
Integrity Warnings
634
Integrity Processor
630
Endpoint Events
520
Runtime Monitor
620
Integrity Events
621
Native Machine Instrumentation
511
Raw Events
611
Endpoint Trust Agent
Device
510
560
System Event Correlator
410
Risk Correlation Matrix
411
Integrity Profile
420
Trust Orchestrator
430
600

FIG. 7A

701

Process Events	
SystemUuid	WorkingSetSize
ProcessID	PeakWorkingSetSize
HashDigest	ReadOpCount
ImageName	WriteOpCount
ImageSize	OtherOpCount
Timestamp	ReadTxCount
Hostname	WriteTxCount
SystemIpAddress	OtherTxCount
DigitalSignature	IOReadOpPerSec
CertificateChain	IOWriteOpPerSec
RegistryWrites	IOOtherOpPerSec
FilesystemWrites	IOReadBytesPerSec
ImagePath	IOWriteBytesPerSec
DEP	IOOtherBytesPerSec
ServiceAccount	Priority
UserModeTime	Restarts
KernelModeTime	ElapsedTime
ThreadCount	PercentProcessorTime
HandleCount	PercentUserTime
PageFaults	PercentPrivilegedTime
PageFaultsPerSec	Watch
PageFileUsage	CommandLine
PeakPageFileUsage	NetworkPorts
VirtualSize	NetworkProtocols

702

Processor Events
UniqueId
SystemUuid
Hostname
PercentageProcessorTime
PercentageUserTime
PercentagePrivilegedTime
LoadPercentage

703

System Events
SystemUuid
Hostname
SystemIpAddress
RegistryWrites
FilesystemWrites
DEP

704

Binary Analysis
HashDigest
ImageName
ImageSize
Timestamp
DigitalSignature
FileVersion
Publisher
C2Protocol
RegistryManipulation
OSManipulation
FileCreation
ProcessCreation
ProcessTermination
Crypto
IPC
Spam
DoS
AntiDbg
RemoteThreadCreation
ThreatLevel

700

FIG. 7B

711

Platform Alerts

[P1]: Excessive CPU Utilization (≥ N%)
[P2]: Excessive Memory Utilization (≥ N%)
[P3]: Excessive I/O Utilization (Operations/Bytes Per Sec)
[P4]: Excessive Page-Faults (≥ N)
[P5]: Excessive Filesystem Manipulations (≥ N)
[P6]: Excessive Registry Manipulations (≥ N)
[P7]: Vulnerability (NIST-SCAP/OVAL policies) Severity (≥ N)
[P8]: Configuration Severity (≥ N)
[P9]: Patch Severity (≥ N)
- Missing Critical Patches for ≥ N Days

[P10]: Compliance (NIST-SCAP/XCCDF) Severity (≥ N)
- PCI, FDCC, …

[P11]: DEP Disabled

713

Grayware Alerts (Watch List)

[G1]: Excessive CPU Utilization (≥ N%)
[G2]: Excessive Memory Utilization (≥ N%)
[G3]: Excessive I/O Utilization (Operations/Bytes Per Sec)
[G4]: Excessive Page-Faults (≥ N)
[G5]: Excessive Page File Usage (≥ N)
[G6]: Excessive Restarts (≥ N)
[G7]: Excessive Read/Write/Other Operations/Transfers
[G8]: Filesystem Manipulations
- In Folders Other Than Working Folder

[G9]: Registry Manipulations (≥ N)
[G10]: Database Manipulations (≥ N)
- Uses Default MySQL, MSSQL, Oracle Ports

[G11]: Intermittent Network Traffic
[G12]: Traffic Encryption
- Uses Port N, or Ephemeral Ports

[G13]: Runs As Privileged Service Account
[G14]: Extensive Command Line
[G15]: DEP Disabled

712

Image Alerts

[I1]: Static Analysis (Threat-Level ≥ N)
[I2]: Runtime Monitor (Threat-Level ≥ N)
- No Digital Signing
- Certificate Chain Unverifiable
- Publisher Unidentified

714

Application Alerts

[A1]: Excessive CPU Utilization (≥ N%)
[A2]: Excessive Memory Utilization (≥ N%)
[A3]: Excessive I/O Utilization (Operations/Bytes Per Sec)
[A4]: Excessive Page-Faults (≥ N)
[A5]: Excessive Page File Usage (≥ N)
[A6]: Excessive Virtual Size (≥ N)
[A7]: Excessive Restarts (≥ N)
[A8]: Excessive Read/Write/Other Operations/Transfers
[A9]: Image Execution Path
- Temporary Folders

[A10]: Low Elapsed Time & High Restarts & File Creations

710

FIG. 7C

721

VM UUID	S1	S2	S3	S4
56 4d ef 2d 3f d4 14 e2-2e 04 c5 34 3a ec ee 65	P_1 … P_4		A_4 … A_6	
65 4d 2f 2d 3f d4 41 e2-2e 04 c5 34 3a ec ee ef		P_3 … P_7	A_3 … P_4	I_2 … I_9
34 5d cf 2d 1f d4 14 e2-2e 04 c5 34 3b ec ee de		P_{11}		
51 4d ef 2d 3f e4 24 c2-2e 04 c5 34 3a ec ee 23	P_7 … P_{10}	P_4	P_3 … A_9	G_4 … G_9
. . .				I_7 … G_{10}
25 d4 ef d2 3f d4 14 e2-2e 04 43 34 3a ec ec 5c	P_7 … P_{10}	P_4	P_3 … A_9	G_4 … G_9

722 System Warning Classes

723 System Warnings

724

[S1]: System Deviated
Platform Alerts [P1, P2, …, Pn]
[S2]: System Duress
Platform Alerts [P1, P2, …, Pn]
[S3]: System Vulnerable
Platform Alerts [P1, P2, …, Pn]
Application Alerts [A1, A2, …, An]
[S4]: System Infected
Image Alerts [I1, I2, …, In]
Grayware Alerts [G1, G2, …, Gn]

Alert = Fn (Attribute, Constraint, Sample Rate, Recurrence, Score, Weight 725

720

FIG. 8

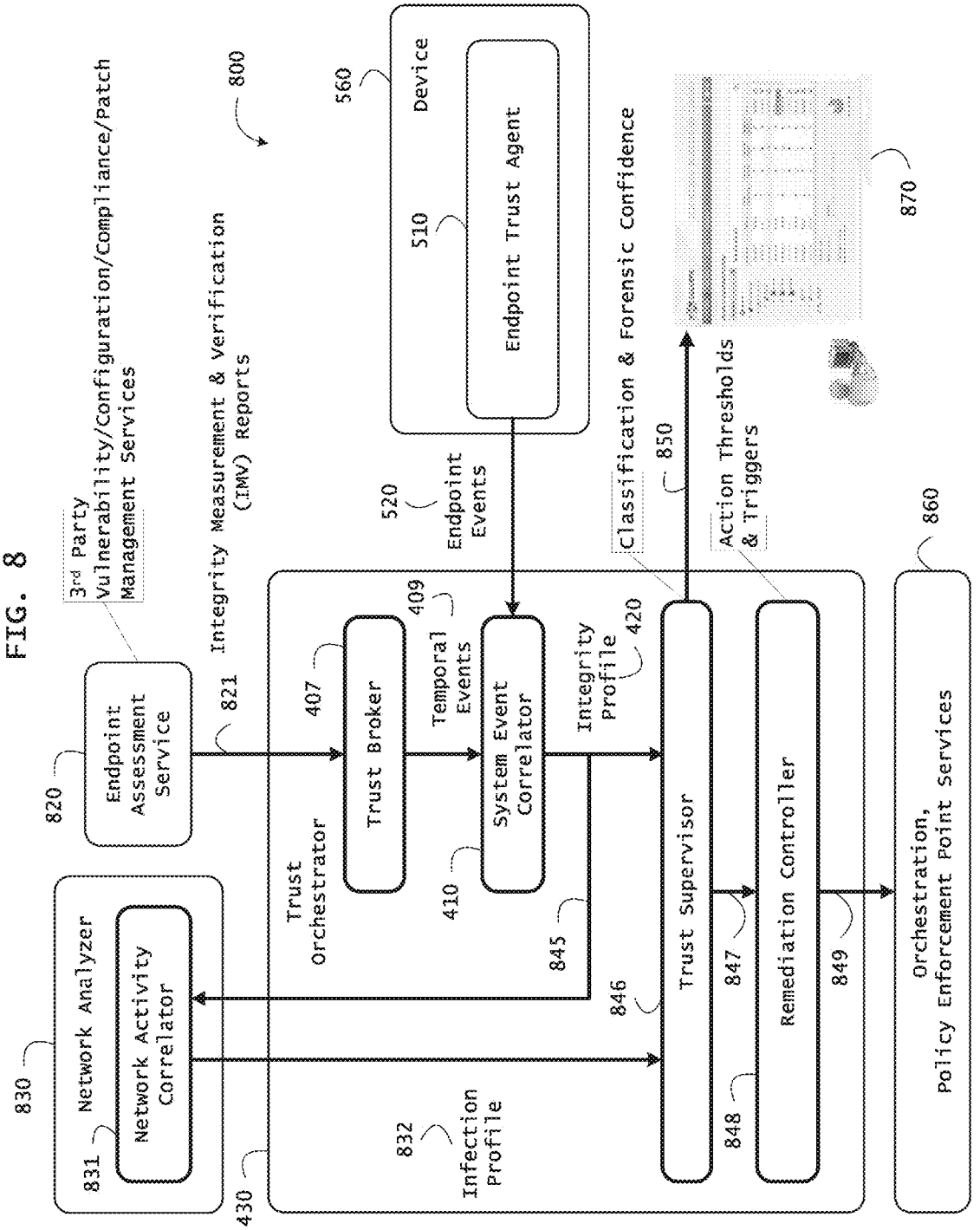

800
3rd Party Vulnerability/Configuration/Compliance/Patch Management Services
Integrity Measurement & Verification (IMV) Reports
560
Device
510
Endpoint Trust Agent
870
520
Endpoint Events
Classification & Forensic Confidence
850
Action Thresholds & Triggers
860
820
Endpoint Assessment Service
821
407
Trust Broker
409
Temporal Events
System Event Correlator
420
Integrity Profile
Trust Orchestrator
410
845
846
Trust Supervisor
847
Remediation Controller
849
Orchestration, Policy Enforcement Point Services
830
Network Analyzer
831
Network Activity Correlator
832
Infection Profile
848
430

FIG. 9

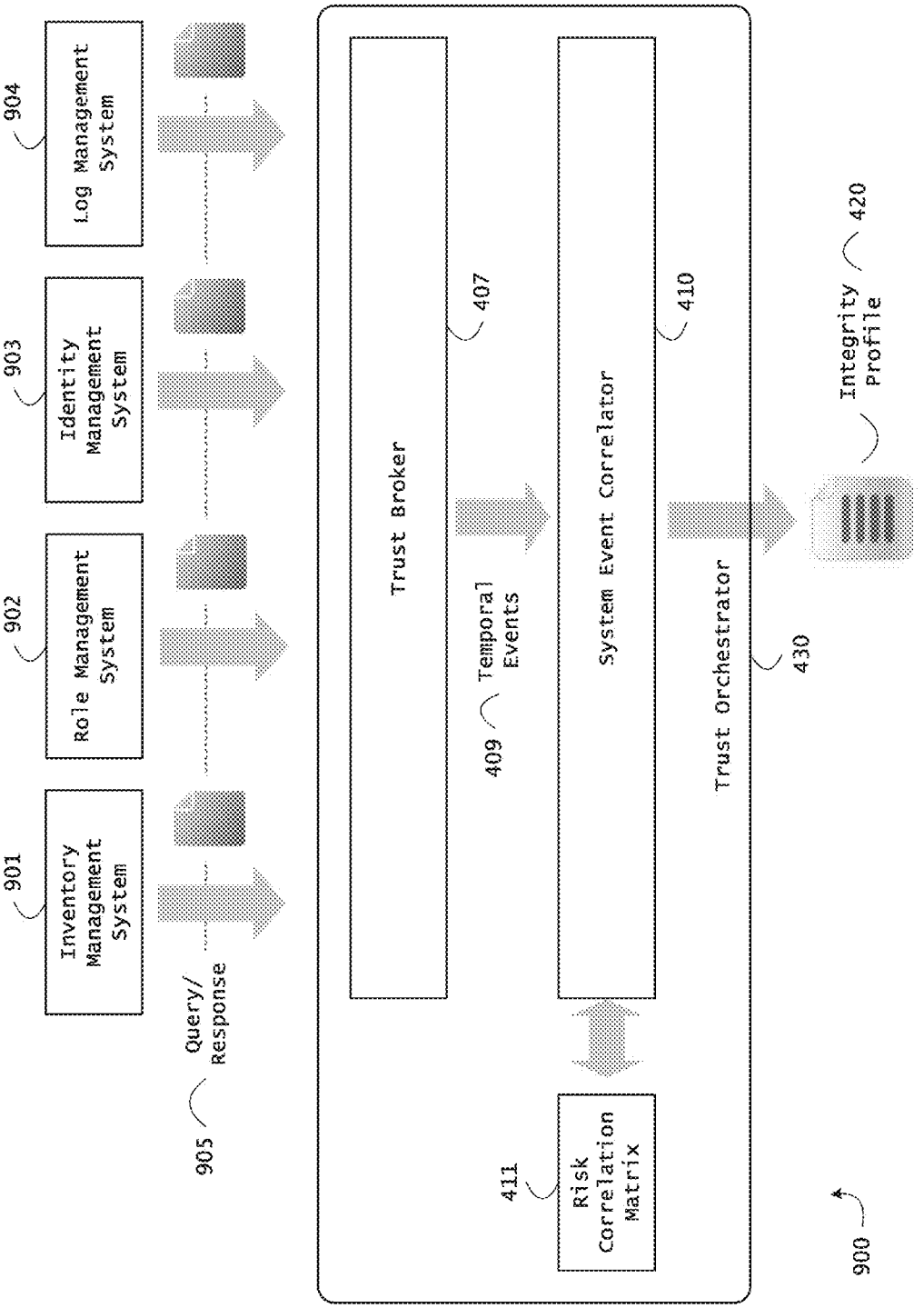

901
Inventory Management System
902
Role Management System
903
Identity Management System
904
Log Management System
905
Query/ Response
Trust Broker
407
409
Temporal Events
System Event Correlator
410
411
Risk Correlation Matrix
Trust Orchestrator
430
Integrity Profile
420
900

FIG. 10

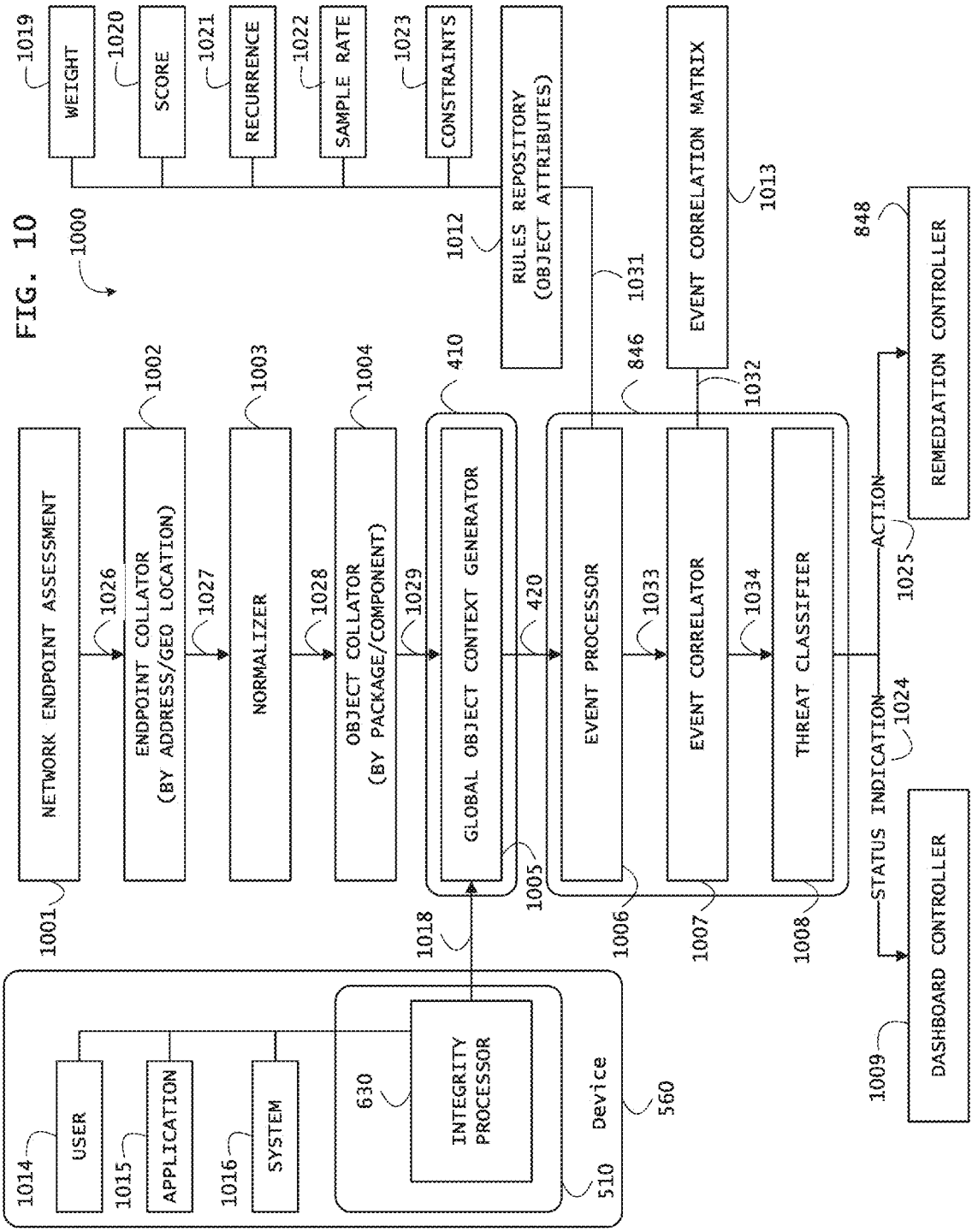
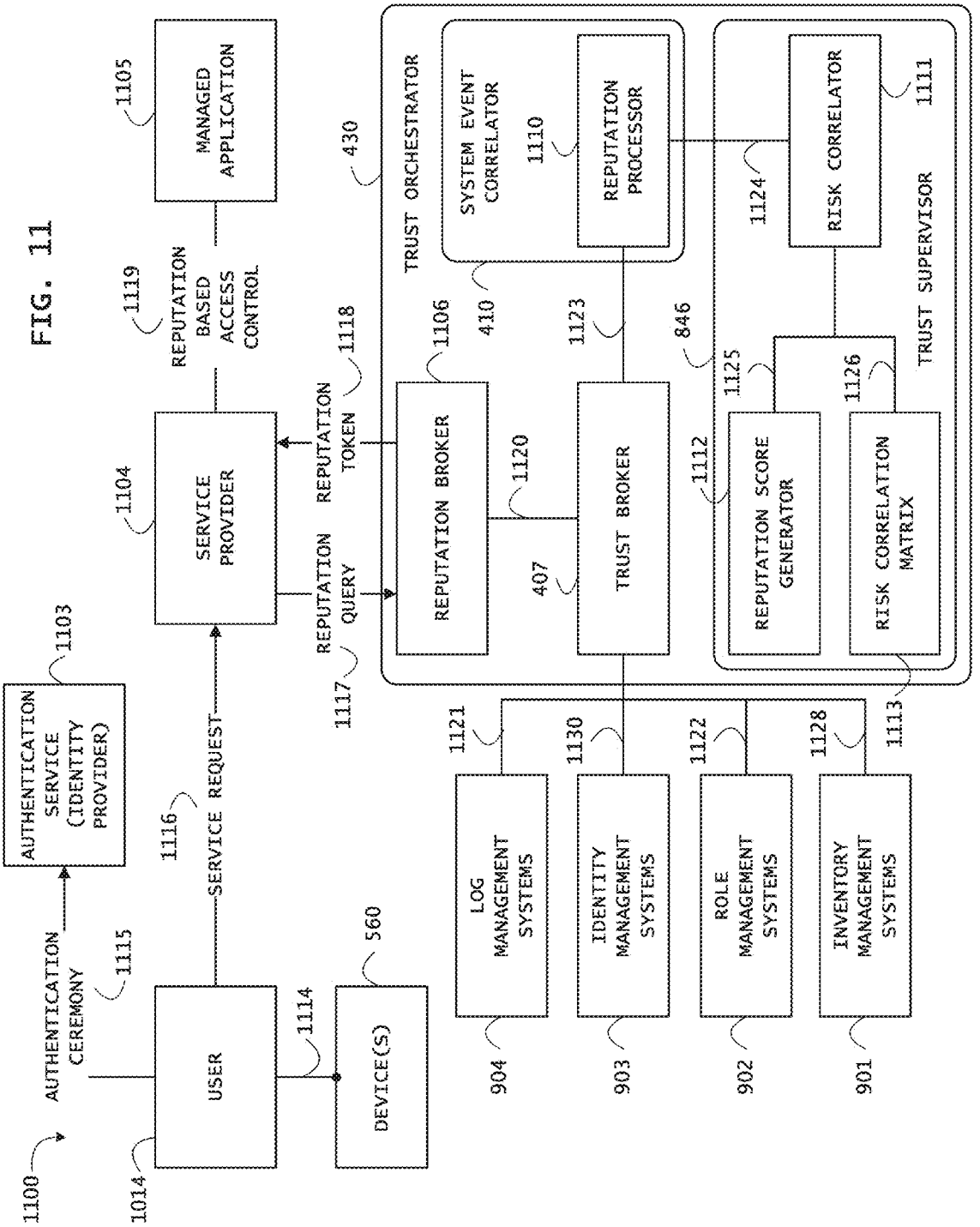

1000
1019
WEIGHT
1020
SCORE
1021
RECURRENCE
1022
SAMPLE RATE
1023
CONSTRAINTS
1012
RULES REPOSITORY (OBJECT ATTRIBUTES)
1031
1013
EVENT CORRELATION MATRIX
848
REMEDIATION CONTROLLER
1001
NETWORK ENDPOINT ASSESSMENT
1026
1002
ENDPOINT COLLATOR (BY ADDRESS/GEO LOCATION)
1027
1003
NORMALIZER
1028
1004
OBJECT COLLATOR (BY PACKAGE/COMPONENT)
1029
410
GLOBAL OBJECT CONTEXT GENERATOR
1005
420
846
1032
EVENT PROCESSOR
1006
1033
EVENT CORRELATOR
1007
1034
THREAT CLASSIFIER
1008
ACTION
1025
STATUS INDICATION
1024
DASHBOARD CONTROLLER
1009
1018
1014
USER
1015
APPLICATION
1016
SYSTEM
630
INTEGRITY PROCESSOR
510
Device
560

FIG. 11


1100
AUTHENTICATION CEREMONY
1115
USER
1014
1114
DEVICE(S)
560
AUTHENTICATION SERVICE (IDENTITY PROVIDER)
1103
1116
SERVICE REQUEST
SERVICE PROVIDER
1104
1119
REPUTATION BASED ACCESS CONTROL
MANAGED APPLICATION
1105
REPUTATION QUERY
1117
REPUTATION TOKEN
1118
TRUST ORCHESTRATOR
430
REPUTATION BROKER
1106
TRUST BROKER
407
1120
SYSTEM EVENT CORRELATOR
410
REPUTATION PROCESSOR
1110
1123
TRUST SUPERVISOR
846
REPUTATION SCORE GENERATOR
1112
1125
RISK CORRELATION MATRIX
1126
RISK CORRELATOR
1124
1111
1113
LOG MANAGEMENT SYSTEMS
904
1121
IDENTITY MANAGEMENT SYSTEMS
903
1130
ROLE MANAGEMENT SYSTEMS
902
1122
INVENTORY MANAGEMENT SYSTEMS
901
1128

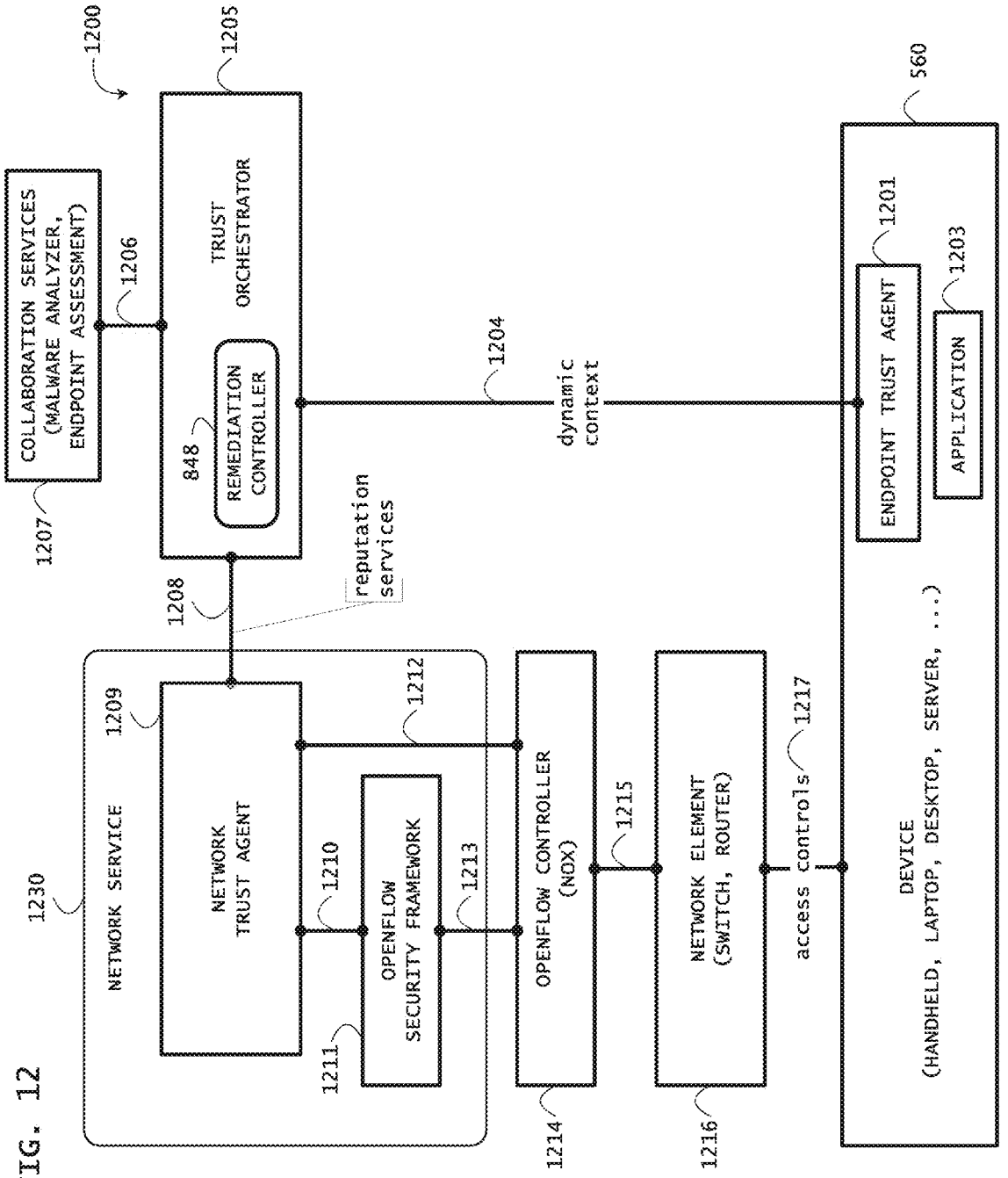

1200
COLLABORATION SERVICES (MALWARE ANALYZER, ENDPOINT ASSESSMENT)
1207
1206
1205
TRUST ORCHESTRATOR
848
REMEDIATION CONTROLLER
1204
dynamic context
560
1201
ENDPOINT TRUST AGENT
1203
APPLICATION
reputation services
1208
1230
NETWORK SERVICE
1209
NETWORK TRUST AGENT
1210
1211
OPENFLOW SECURITY FRAMEWORK
1212
1213
OPENFLOW CONTROLLER (NOX)
1214
1215
NETWORK ELEMENT (SWITCH, ROUTER)
1216
1217
access controls
DEVICE (HANDHELD, LAPTOP, DESKTOP, SERVER, ...)

FIG. 12

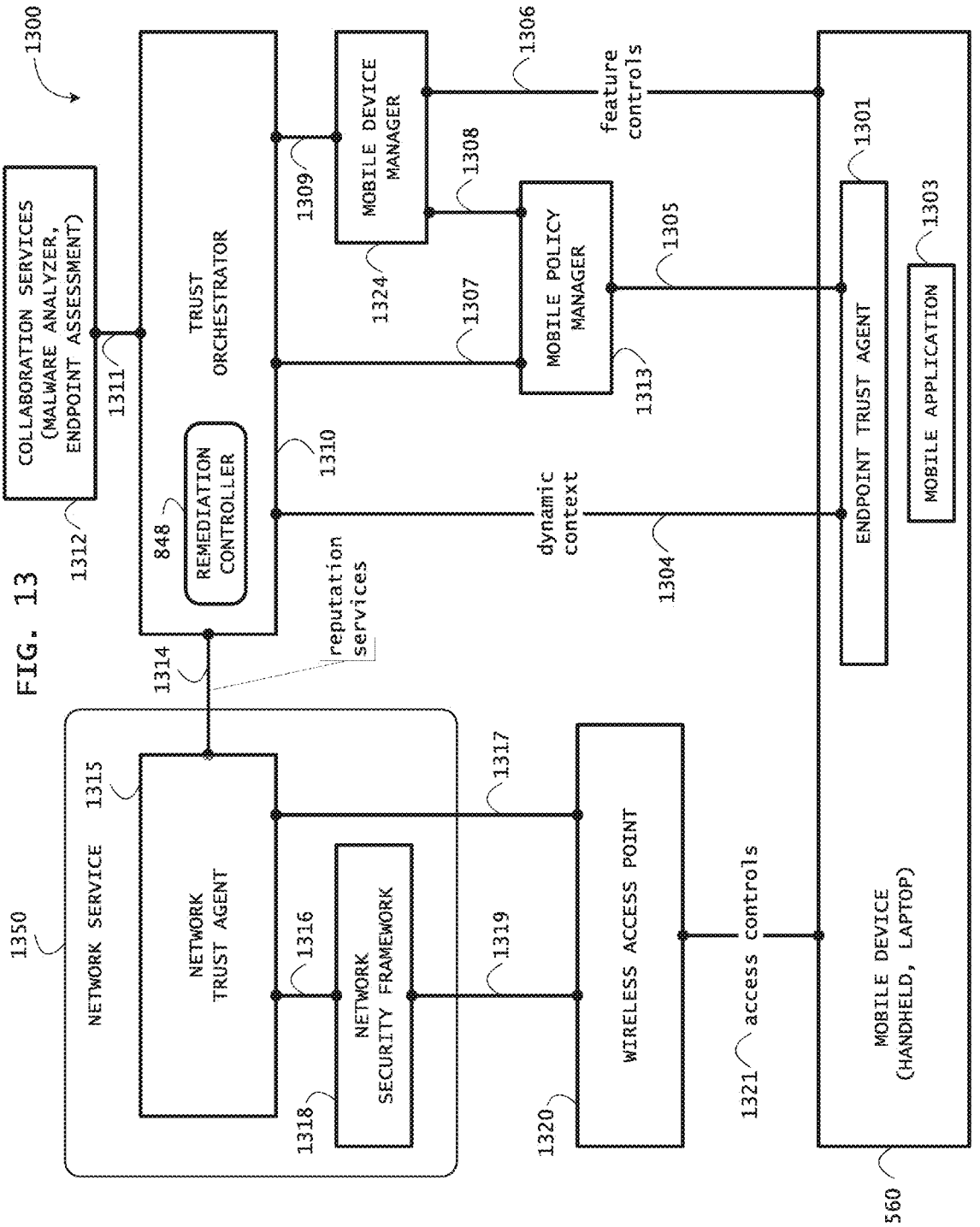

1300
COLLABORATION SERVICES (MALWARE ANALYZER, ENDPOINT ASSESSMENT)
1312
1311
TRUST ORCHESTRATOR
848
REMEDIATION CONTROLLER
1314
reputation services
1309
MOBILE DEVICE MANAGER
1324
1306
feature controls
1308
1307
MOBILE POLICY MANAGER
1313
1305
1310
dynamic context
1304
1301
ENDPOINT TRUST AGENT
1303
MOBILE APPLICATION
1350
NETWORK SERVICE
1315
NETWORK TRUST AGENT
1316
NETWORK SECURITY FRAMEWORK
1318
1317
1319
WIRELESS ACCESS POINT
1320
access controls
1321
MOBILE DEVICE (HANDHELD, LAPTOP)
560

FIG. 13

FIG. 14

1400
1401
dba.com
NALA
DC 1
Host 1
Host 2
Host 3
DC 2
DC 3
APAC
EMEA
1402
Host 2
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1440
1450
h2vm1
h2vm2
h2vm3
h2vm4
h2vm5
h2vm6
h2vm7
h2vm8
h2vm9
h2vm3

FIG. 15

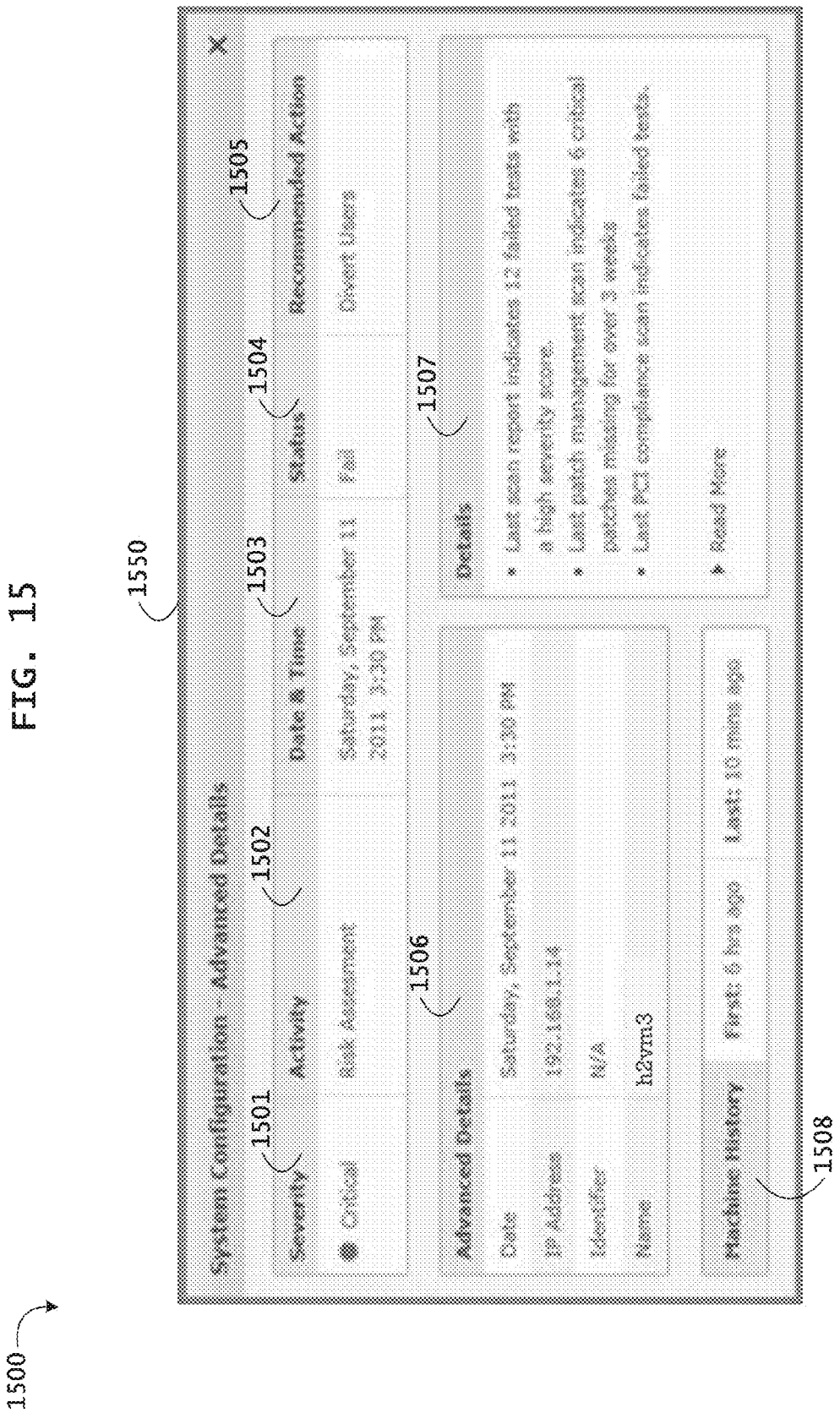

1500
1550
System Configuration - Advanced Details
1501
Severity
1502
Activity
1503
Date & Time
1504
Status
1505
Recommended Action
Critical
Risk Assessment
Saturday, September 11 2011 3:30 PM
Fail
Event Users
1506
Advanced Details
Date
Saturday, September 11 2011 3:30 PM
IP Address
192.168.1.14
Identifier
N/A
Name
h2vm3
1507
Details
* Last scan report indicates 12 failed tests with a high severity score.
* Last patch management scan indicates 6 critical patches missing for over 3 weeks
* Last PCI compliance scan indicates failed tests.
Read More
Machine History
First: 6 hrs ago
Last: 10 mins ago
1508

FIG. 16

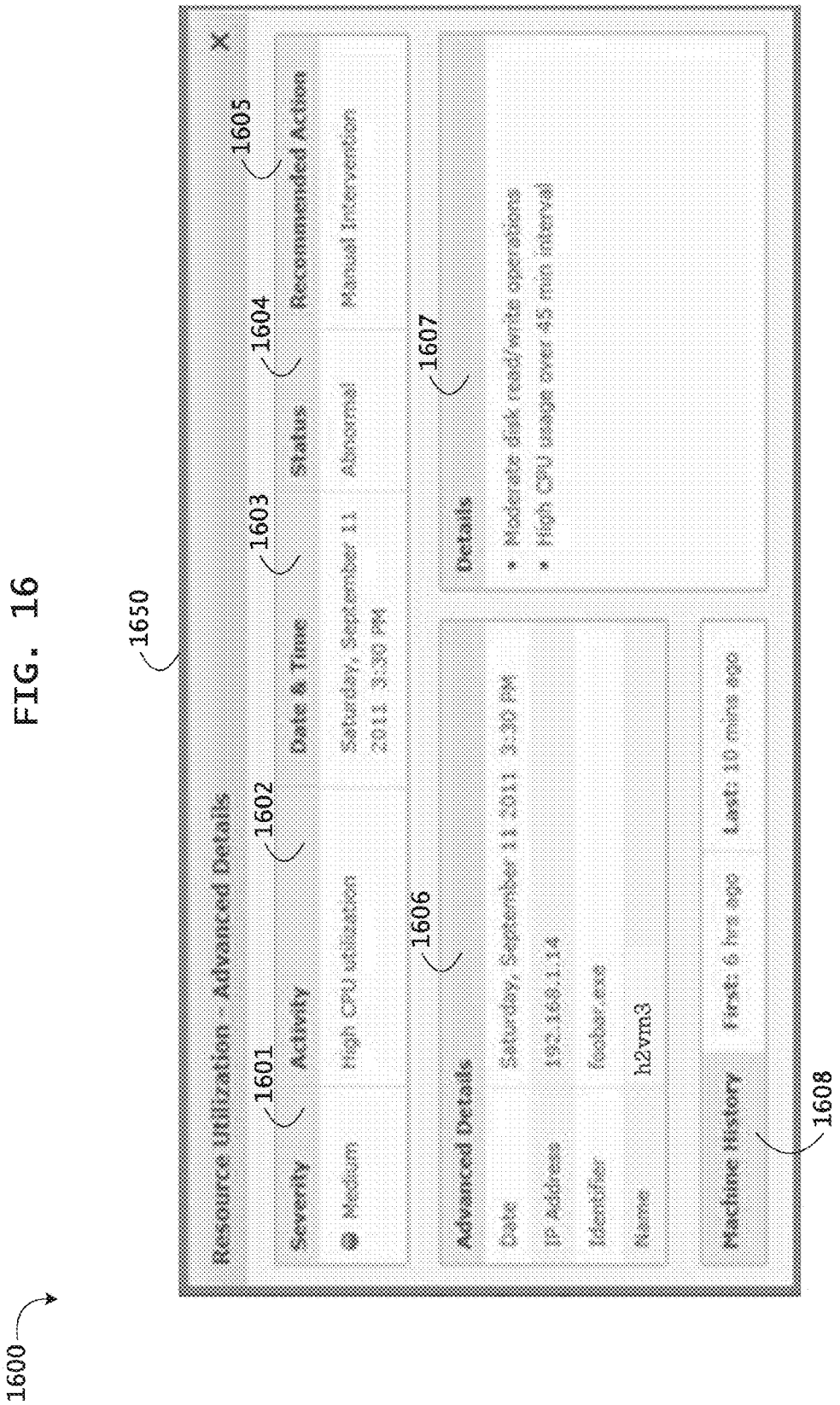

1600
1650
Resource Utilization - Advanced Details
Severity
Activity
Date & Time
Status
Recommended Action
1601
1602
1603
1604
1605
Medium
High CPU utilization
Saturday, September 11 2011 3:30 PM
Abnormal
Manual Intervention
Advanced Details
Date
Saturday, September 11 2011 3:30 PM
IP Address
192.168.1.14
Identifier
Name
h2vm3
1606
Details
* Moderate disk read/write operations
* High CPU usage over 45 min interval
1607
Machine History
First: 6 hrs ago
Last: 10 mins ago
1608

FIG. 17

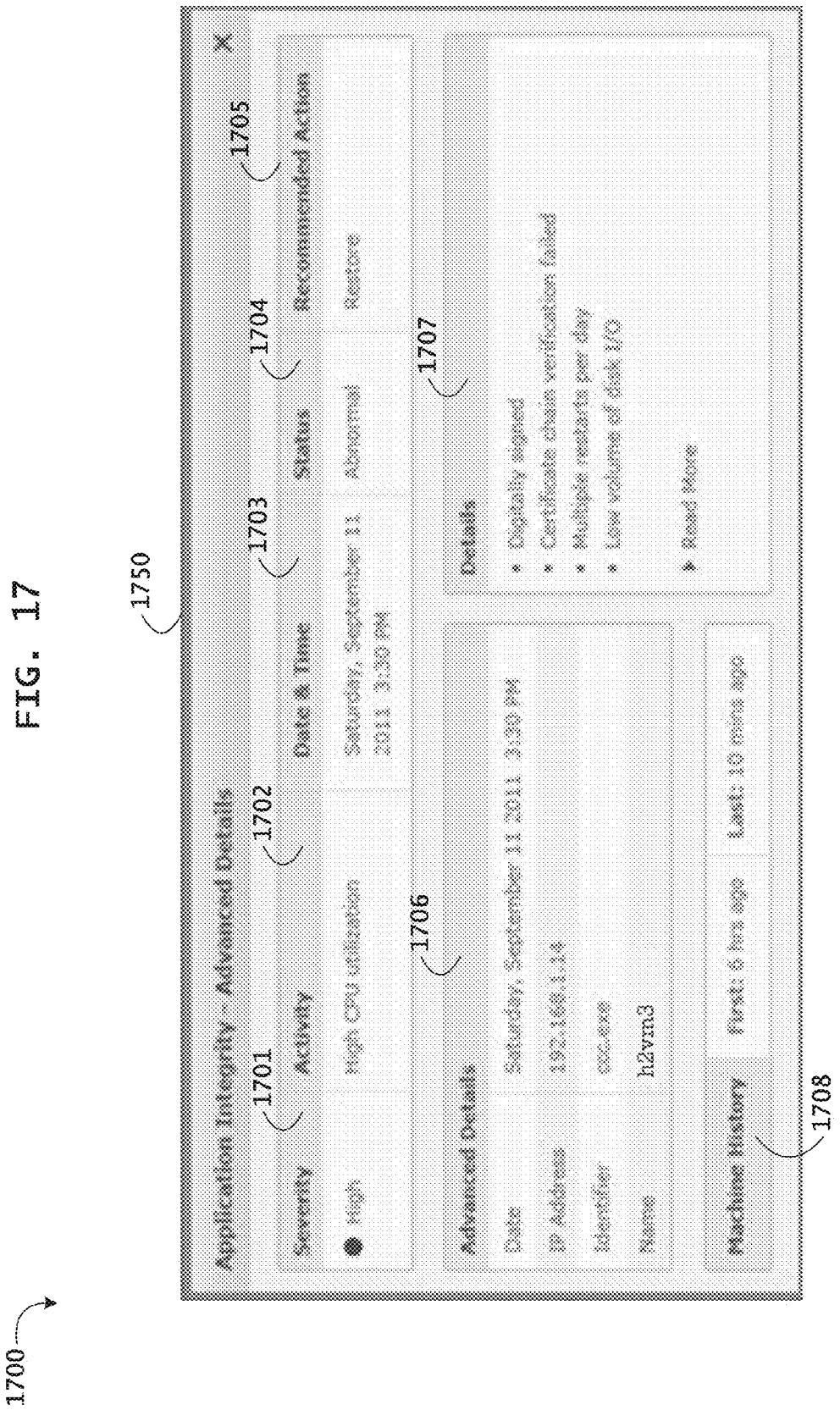

1700
1750
Application Integrity - Advanced Details
1701
Severity
Activity
1702
High
High CPU utilization
1703
Date & Time
Saturday, September 11 2011 3:30 PM
1704
Status
Abnormal
1705
Recommended Action
Restore
1706
Advanced Details
Date
Saturday, September 11 2011 3:30 PM
IP Address
192.168.1.14
Identifier
cccccccc
Name
h2vm3
1707
Details
Digitally signed
Certificate chain verification failed
Multiple restarts per day
Low volume of disk I/O
Read More
1708
Machine History
First: 6 hrs ago
Last: 10 mins ago

FIG. 18

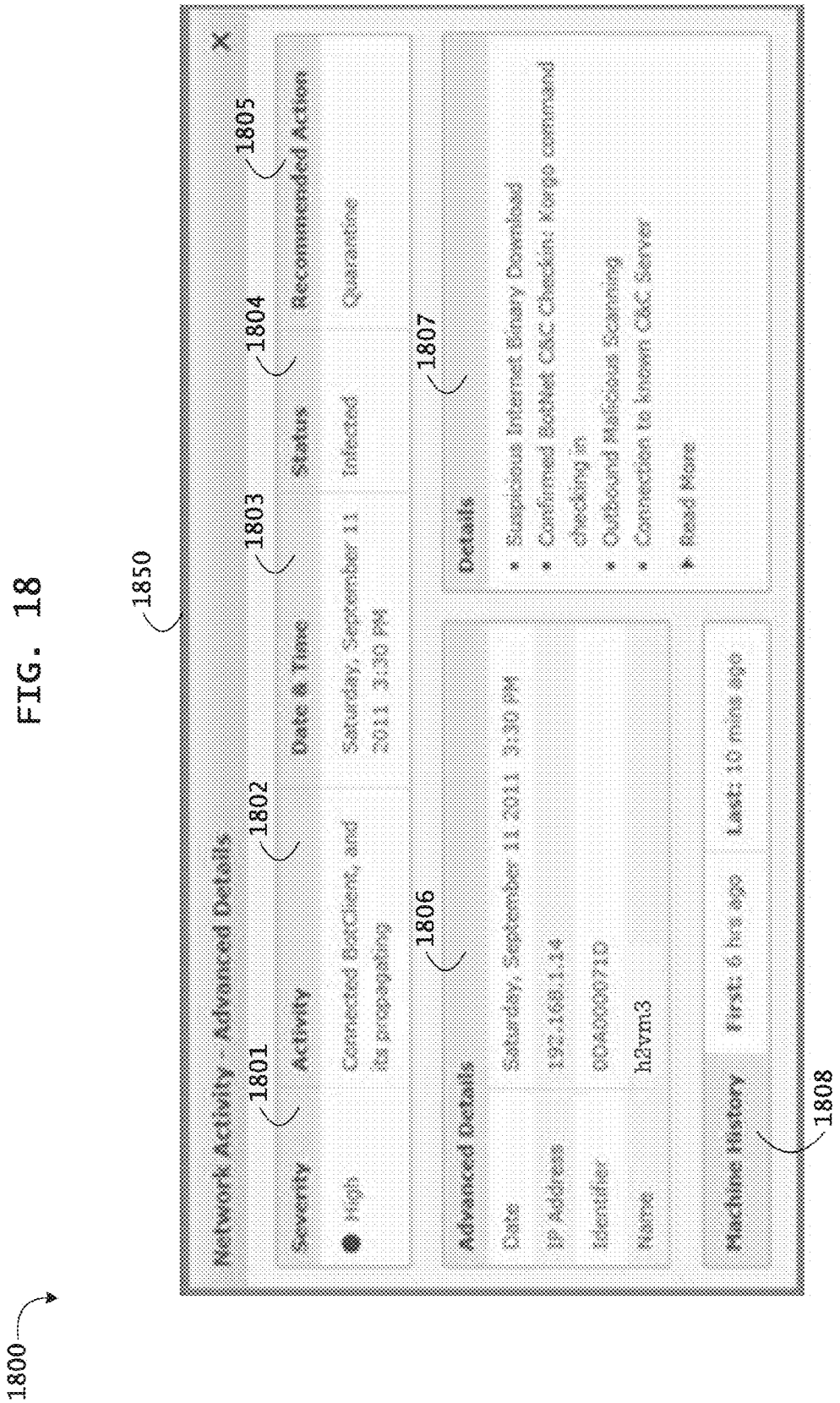

1800
1850
1801
1802
1803
1804
1805
1806
1807
1808
Network Activity - Advanced Details
Severity
Activity
Date & Time
Status
Recommended Action
High
Connected BotClient, and its propagating
Saturday, September 11 2011 3:30 PM
Infected
Quarantine
Advanced Details
Date
Saturday, September 11 2011 3:30 PM
IP Address
192.168.1.14
Identifier
00A0000710
Name
h2vm3
Machine History
First: 6 hrs ago
Last: 10 mins ago
Details
Suspicious Internet Binary Download
Confirmed BotNet C&C Checkin: Korgo command checking in
Outbound Malicious Scanning
Connection to known C&C Server
Read More

FIG. 19

1900
1901
Receive, by the endpoint runtime monitor, raw events from the native device and/or platform instrumentation
1902
Send, by the endpoint runtime monitor, image file and attributes to the trust broker at the trust orchestrator for specialized image analysis
1903
Validate, by the trust broker at the trust orchestrator, the image file based on received attributes
1904
Send, by the trust broker, of the received image file to the malware analyzer for specialized static and dynamic image introspection
1905
Generate and send, by the trust broker, based on received diagnosis an image profile to the endpoint runtime monitor
1906
Generate and send, by the endpoint runtime monitor, events to the integrity processor
1907
Process and map, by the endpoint integrity processor, received events to alerts using rulesets
1908
Generate and send, by the endpoint integrity processor, warnings using an event correlation matrix to the trust orchestrator as endpoint events
1909
Receive, at the trust orchestrator by the system event correlator, endpoint events from the endpoint integrity processor
1910
Receive, at the trust orchestrator by the trust broker, network endpoint integrity measurement and verification reports
1911
Receive, at the trust orchestrator by the system event correlator, temporal events from the trust broker
1912
Correlate, at the trust orchestrator by the system event correlator, endpoint and temporal events; and generate an integrity profile for the device
1913
Send, at the trust orchestrator by the system event correlator, integrity profile of the device to the trust supervisor
1914
Send, by the network activity correlator, infection profiles to the trust supervisor
1915
Process, at the trust orchestrator by the trust supervisor, received integrity and infection profiles for classification of warnings based on forensic confidence for threat identification on the device
1916
Send, at the trust orchestrator by the trust supervisor, to the remediation controller actions to be performed on the infected device
1917
Process, at the trust orchestrator by the remediation controller, received action request on the infected device; and send directives based on configured thresholds and triggers to system orchestration and network security services

FIG. 20

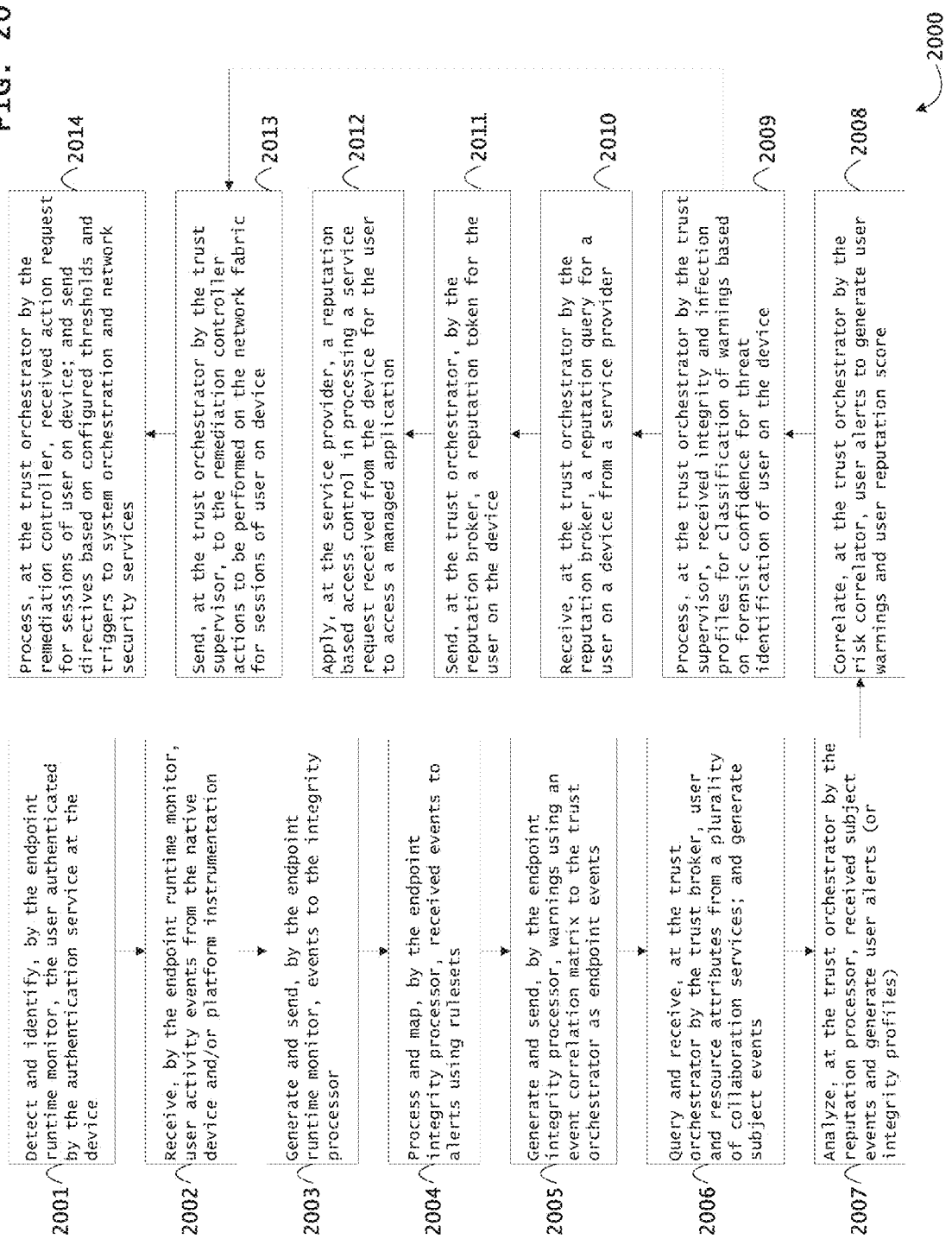

2000
2001
Detect and identify, by the endpoint runtime monitor, the user authenticated by the authentication service at the device
2002
Receive, by the endpoint runtime monitor, user activity events from the native device and/or platform instrumentation
2003
Generate and send, by the endpoint runtime monitor, events to the integrity processor
2004
Process and map, by the endpoint integrity processor, received events to alerts using rulesets
2005
Generate and send, by the endpoint integrity processor, warnings using an event correlation matrix to the trust orchestrator as endpoint events
2006
Query and receive, at the trust orchestrator by the trust broker, user and resource attributes from a plurality of collaboration services; and generate subject events
2007
Analyze, at the trust orchestrator by the reputation processor, received subject events and generate user alerts (or integrity profiles)
2008
Correlate, at the trust orchestrator by the risk correlator, user alerts to generate user warnings and user reputation score
2009
Process, at the trust orchestrator by the trust supervisor, received integrity and infection profiles for classification of warnings based on forensic confidence for threat identification of user on the device
2010
Receive, at the trust orchestrator by the reputation broker, a reputation query for a user on a device from a service provider
2011
Send, at the trust orchestrator, by the reputation broker, a reputation token for the user on the device
2012
Apply, at the service provider, a reputation based access control in processing a service request received from the device for the user to access a managed application
2013
Send, at the trust orchestrator by the trust supervisor, to the remediation controller actions to be performed on the network fabric for sessions of user on device
2014
Process, at the trust orchestrator by the remediation controller, received action request for sessions of user on device; and send directives based on configured thresholds and triggers to system orchestration and network security services

FIG. 21

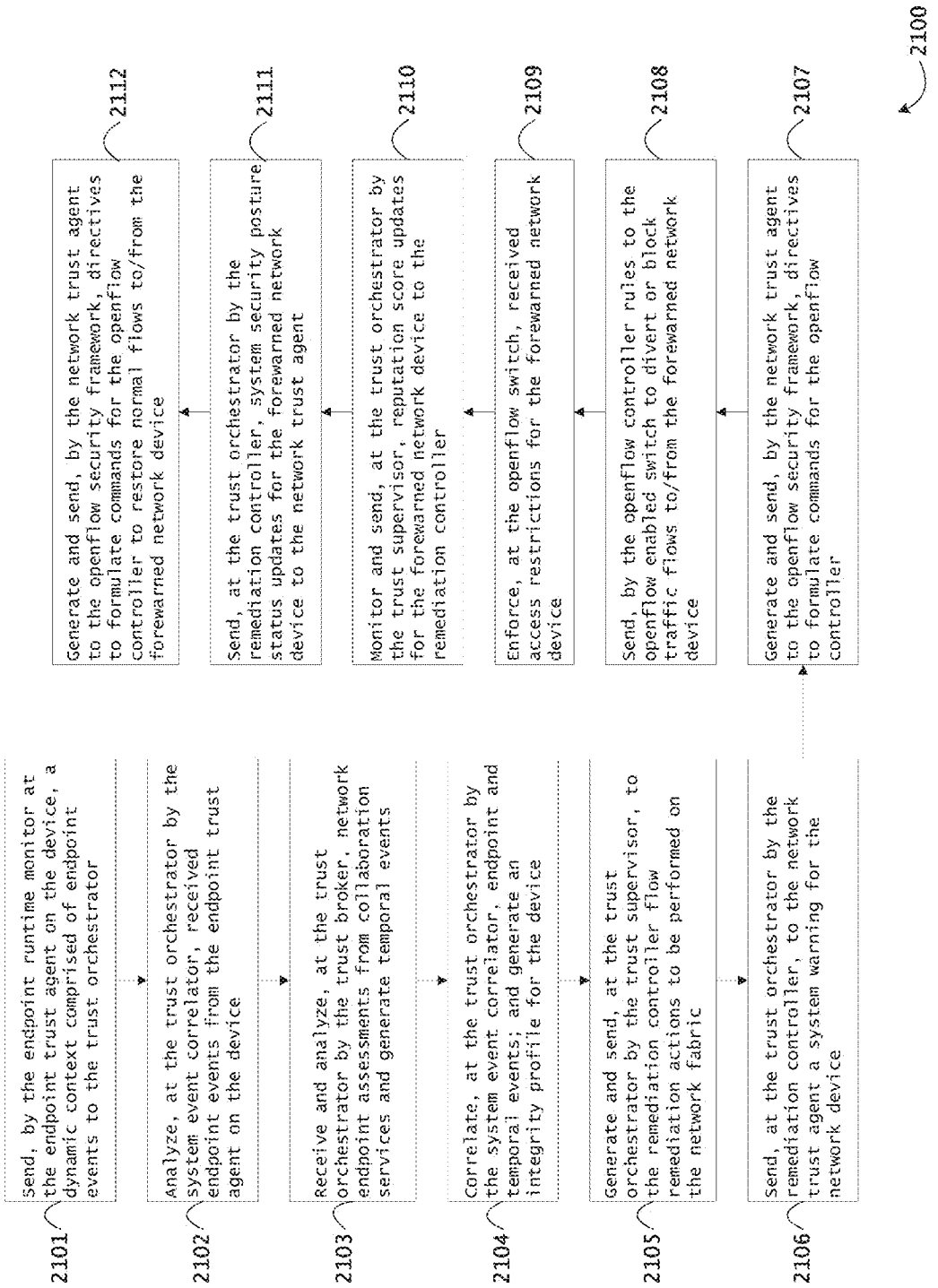

2100
2101
Send, by the endpoint runtime monitor at the endpoint trust agent on the device, a dynamic context comprised of endpoint events to the trust orchestrator
2102
Analyze, at the trust orchestrator by the system event correlator, received endpoint events from the endpoint trust agent on the device
2103
Receive and analyze, at the trust orchestrator by the trust broker, network endpoint assessments from collaboration services and generate temporal events
2104
Correlate, at the trust orchestrator by the system event correlator, endpoint and temporal events; and generate an integrity profile for the device
2105
Generate and send, at the trust orchestrator by the trust supervisor, to the remediation controller flow remediation actions to be performed on the network fabric
2106
Send, at the trust orchestrator by the remediation controller, to the network trust agent a system warning for the network device
2107
Generate and send, by the network trust agent to the openflow security framework, directives to formulate commands for the openflow controller
2108
Send, by the openflow controller rules to the openflow enabled switch to divert or block traffic flows to/from the forewarned network device
2109
Enforce, at the openflow switch, received access restrictions for the forewarned network device
2110
Monitor and send, at the trust orchestrator by the trust supervisor, reputation score updates for the forewarned network device to the remediation controller
2111
Send, at the trust orchestrator by the remediation controller, system security posture status updates for the forewarned network device to the network trust agent
2112
Generate and send, by the network trust agent to the openflow security framework, directives to formulate commands for the openflow controller to restore normal flows to/from the forewarned network device

FIG. 22

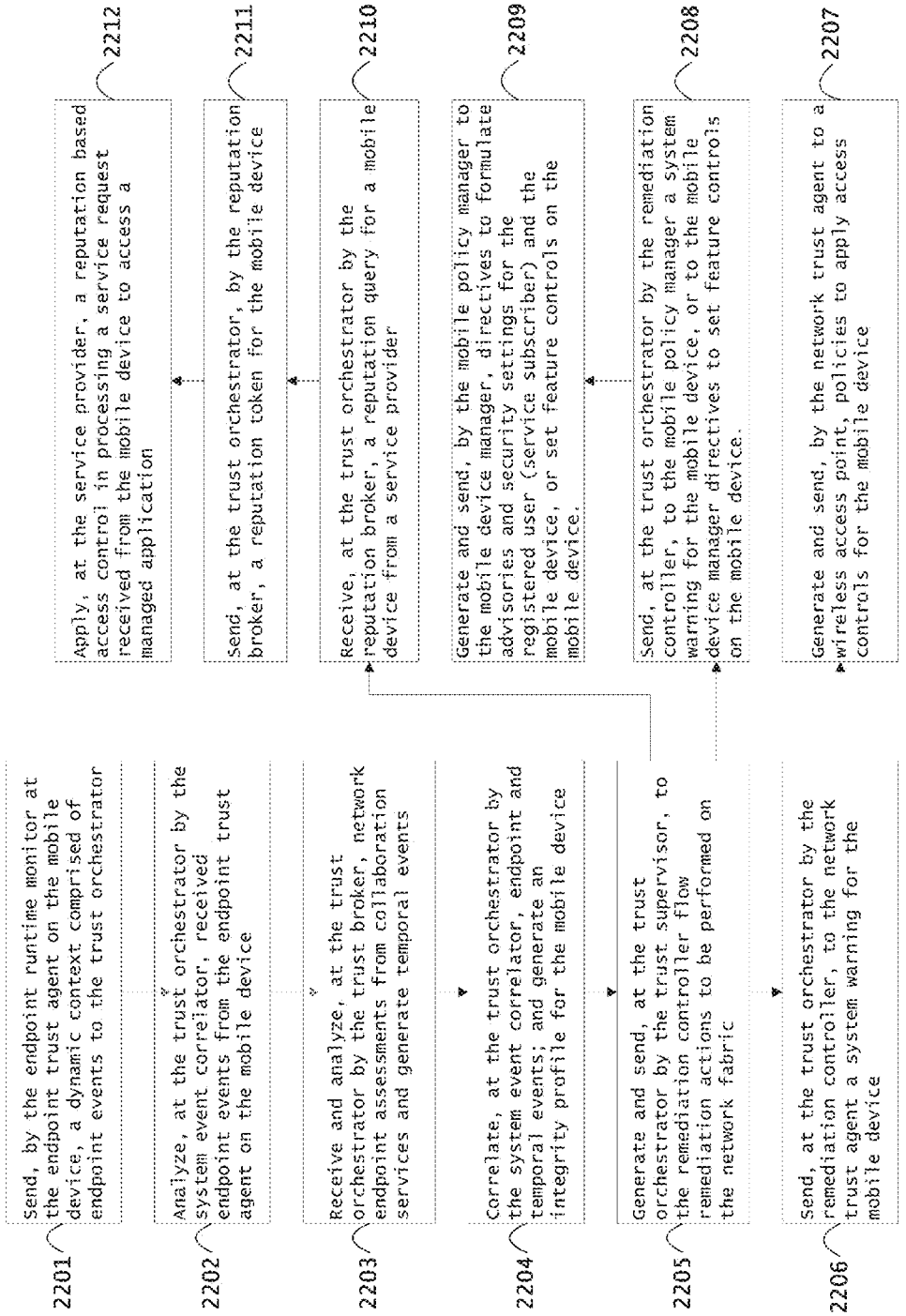

2201
Send, by the endpoint runtime monitor at the endpoint trust agent on the mobile device, a dynamic context comprised of endpoint events to the trust orchestrator
2202
Analyze, at the trust orchestrator by the system event correlator, received endpoint events from the endpoint trust agent on the mobile device
2203
Receive and analyze, at the trust orchestrator by the trust broker, network endpoint assessments from collaboration services and generate temporal events
2204
Correlate, at the trust orchestrator by the system event correlator, endpoint and temporal events; and generate an integrity profile for the mobile device
2205
Generate and send, at the trust orchestrator by the trust supervisor, to the remediation controller flow remediation actions to be performed on the network fabric
2206
Send, at the trust orchestrator by the remediation controller, to the network trust agent a system warning for the mobile device
2200
2212
Apply, at the service provider, a reputation based access control in processing a service request received from the mobile device to access a managed application
2211
Send, at the trust orchestrator, by the reputation broker, a reputation token for the mobile device
2210
Receive, at the trust orchestrator by the reputation broker, a reputation query for a mobile device from a service provider
2209
Generate and send, by the mobile policy manager to the mobile device manager, directives to formulate advisories and security settings for the registered user (service subscriber) and the mobile device, or set feature controls on the mobile device.
2208
Send, at the trust orchestrator by the remediation controller, to the mobile policy manager a system warning for the mobile device, or to the mobile device manager directives to set feature controls on the mobile device.
2207
Generate and send, by the network trust agent to a wireless access point, policies to apply access controls for the mobile device

FIG. 23

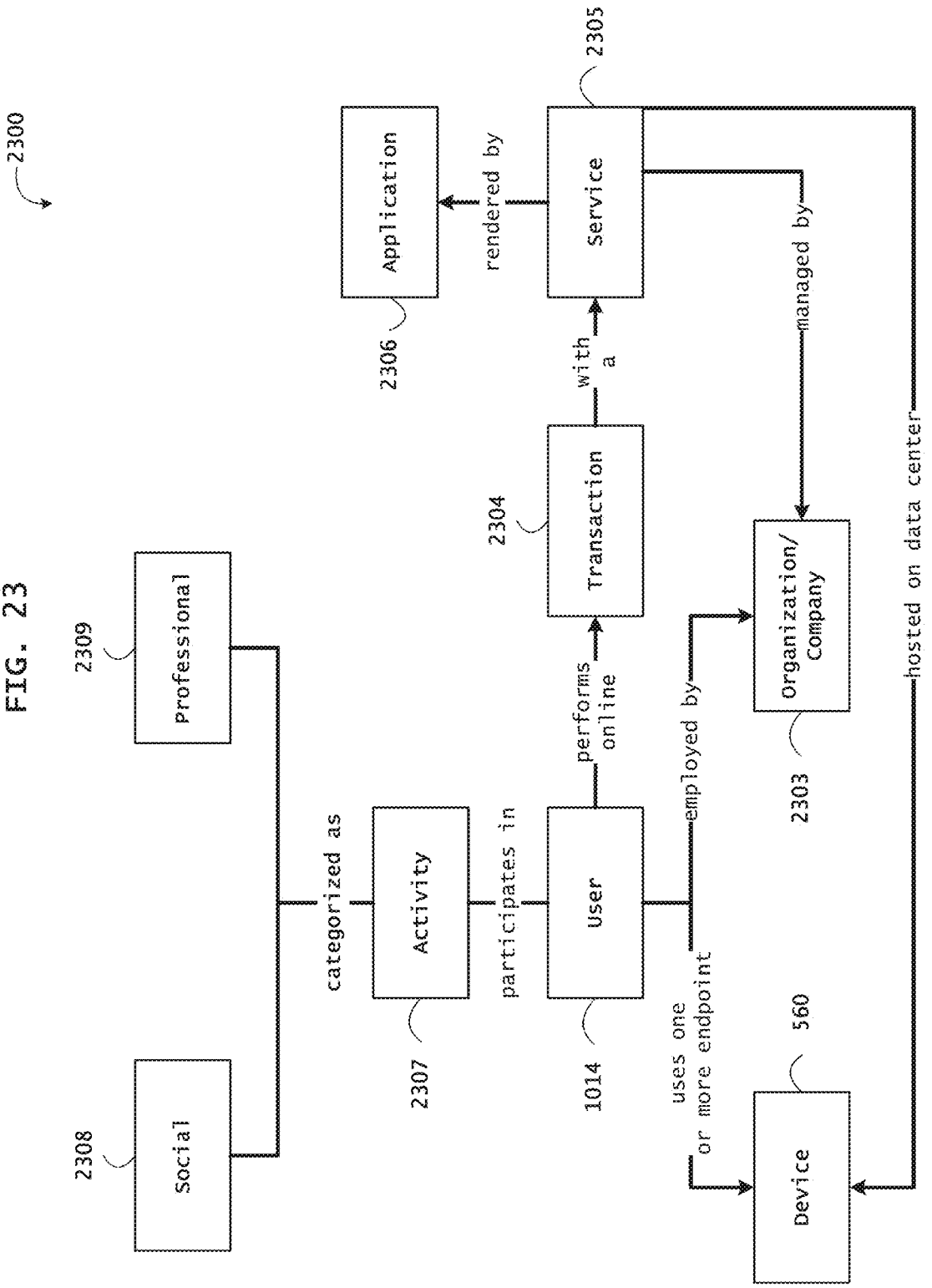

2300
2309
Professional
2308
Social
categorized as
2307
Activity
participates in
1014
User
performs online
2304
Transaction
with a
2306
Application
rendered by
2305
Service
managed by
Organization/ Company
2303
employed by
uses one or more endpoint
560
Device
hosted on data center

FIG. 24

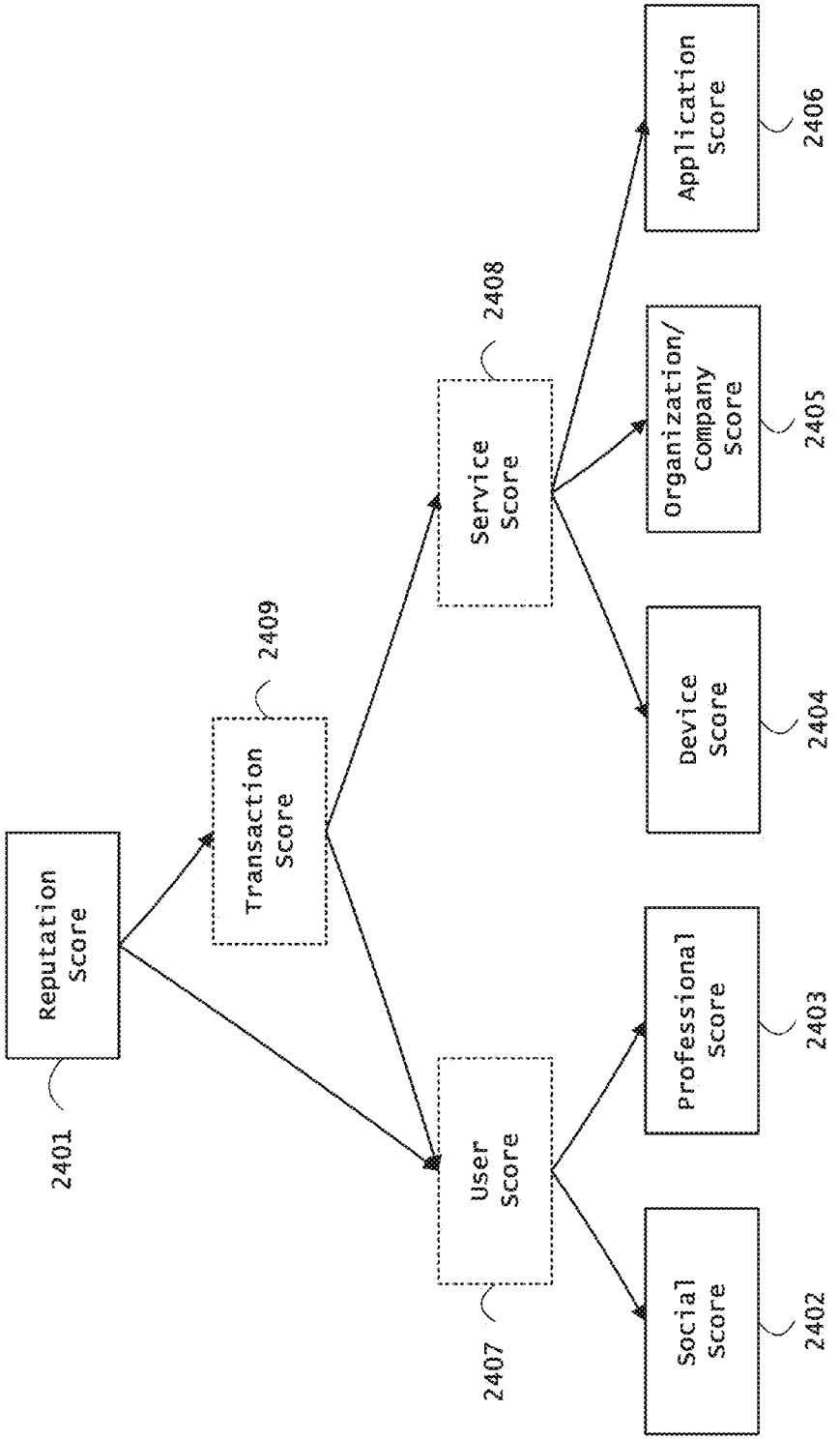

2400
Reputation Score
2401
Transaction Score
2409
User Score
2407
Service Score
2408
Social Score
2402
Professional Score
2403
Device Score
2404
Organization/ Company Score
2405
Application Score
2406

FIG. 25

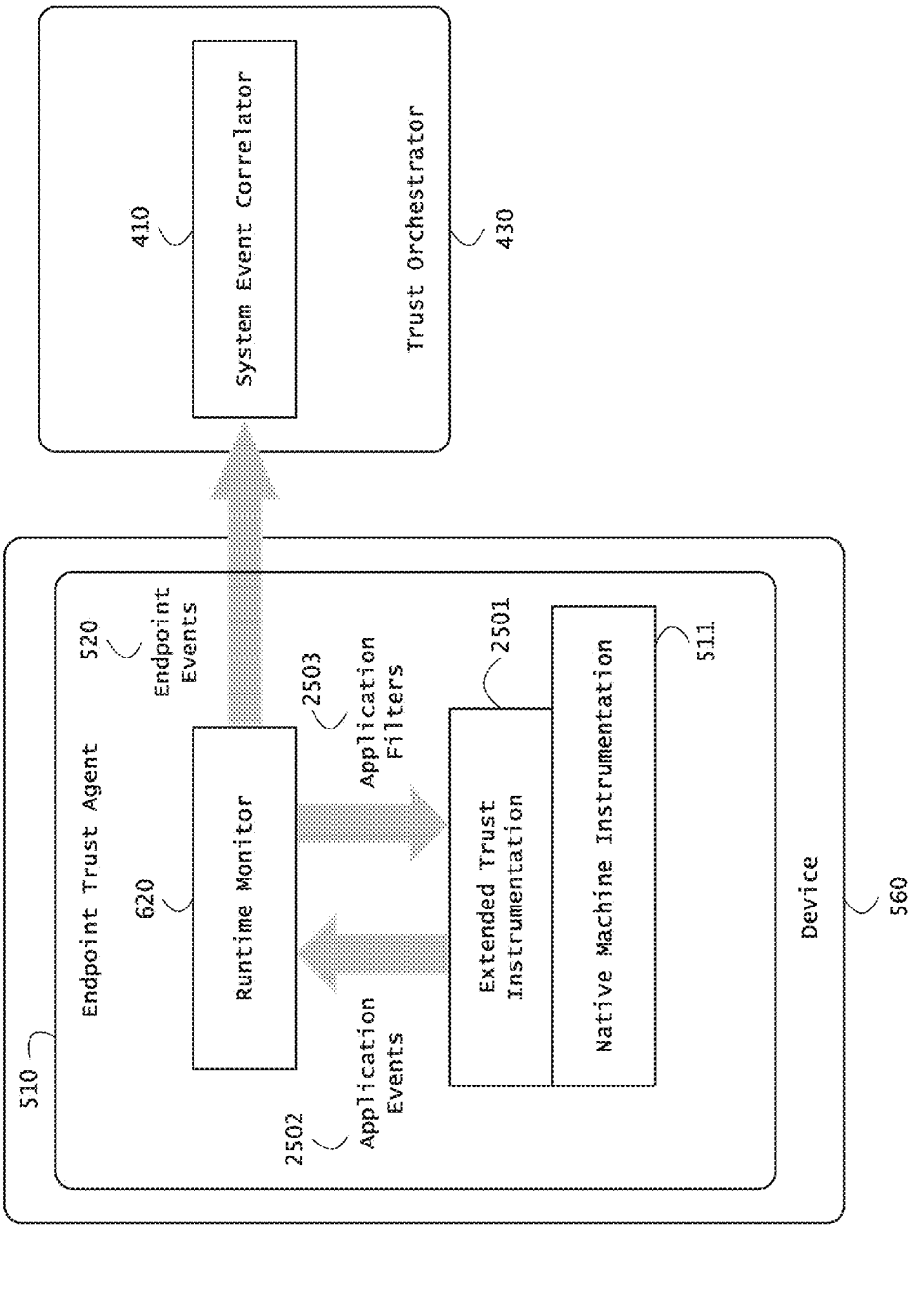
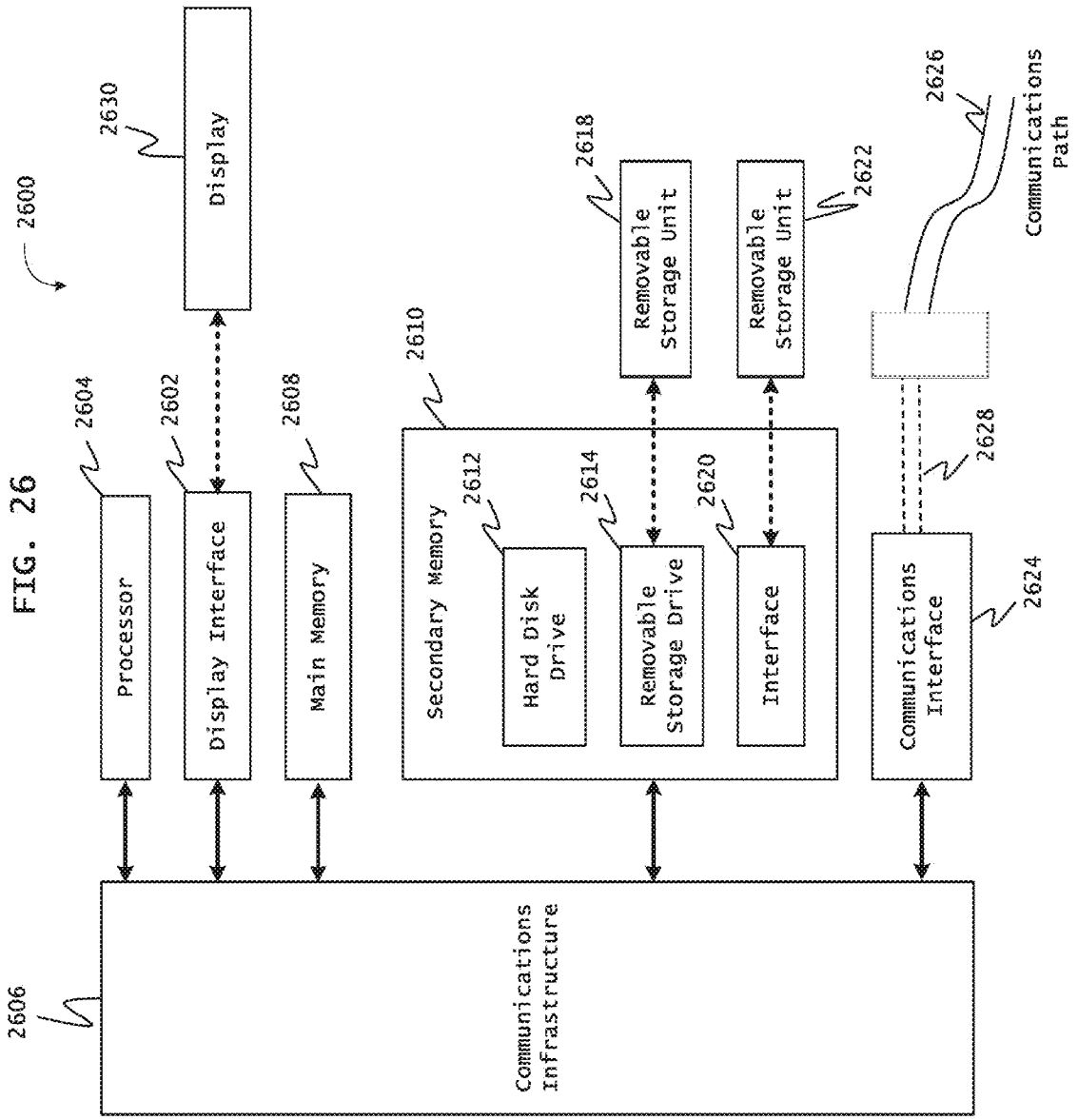

2500
510
Endpoint Trust Agent
520
Endpoint Events
620
Runtime Monitor
2502
Application Events
2503
Application Filters
2501
Extended Trust Instrumentation
511
Native Machine Instrumentation
Device
560
410
System Event Correlator
Trust Orchestrator
430

FIG. 26


2600
2630
Display
2604
Processor
2602
Display Interface
2608
Main Memory
2610
Secondary Memory
2612
Hard Disk Drive
2614
Removable Storage Drive
2620
Interface
2618
Removable Storage Unit
2622
Removable Storage Unit
2626
Communications Path
2628
2624
Communications Interface
2606
Communications Infrastructure

SYSTEMS AND METHODS FOR THREAT IDENTIFICATION AND REMEDIATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Appl. No. 61/641,007 entitled "System and Method for Operational Integrity Attestation," filed May 1, 2012, incorporated by reference herein in its entirety.

BACKGROUND OF THE DISCLOSURE

[0002] 1. Field of the Disclosure

[0003] The present disclosure relates to the field of data center virtualization and, more particularly, to systems and methods for providing dynamic operational integrity attestation of application security and a user reputation at runtime.

[0004] 2. Description of the Related Art

[0005] One recent trend in computing is the trend towards virtualization and cloud computing in which, for example, enterprise software is no longer owned by the customer, but instead the enterprise's Information Technology (IT) infrastructure can be provided by a third party and enterprise software applications are sold as service offerings.

[0006] Traditional legacy and currently available security technologies, such as next-generation anti-virus software, network firewalls, and intrusion detection/prevention systems, operate based on signatures, protocol anomalies or virtual execution in a sandbox to monitor threats and attacks. However, once a target of an attack or threat (i.e., a 'target system' or 'target platform') becomes infected or compromised, many of these technologies have been proven relatively ineffective in protecting systems and preventing data breaches or service disruptions. Emerging threats and attacks can exhibit a low and slow mode of operation and can be signature-less in order to evade traditional detection and defense technologies. Further, these technologies are often agnostic to the runtime operational integrity of computer workloads on the target (victim) systems and therefore often do not offer any level of remediation to service the affected target systems. As such, many traditional security technologies merely provide coarse-grained access controls limited to a simple allow or deny decision logic.

[0007] Many enterprises and organizations are moving there IT infrastructures to cloud computing environments (from self-managed on-premise data centers to service-provider managed outsourced virtual data centers), wherein which third parties may provide shared computing resources and applications running on those resources. They are being offered as services to a plurality of customers. The move by companies to cloud computing environments are increasing for various reasons, including the need for increased computing power, increased storage capacity, and/or increased network bandwidth, among others. Enterprise applications and mission critical applications may be executed in the cloud. Without adequate device, system, and application security, the cloud can compromise these applications, potentially causing large financial losses. Data confidentiality, data integrity and data availability can be maintained in the cloud computing environment even when such applications may be controlled by these third parties. The cloud may enable traditional information technology devices, systems and applications to transparently execute from these service-providers managed outsourced virtual data centers. As newer technologies emerge, the cloud infrastructure may evolve transparent to and scalable with enterprise operations. Security in such environments may be an emerging challenge. For example, virtualized, cloud computing on-demand, and elastic models require dynamic security orchestration at both the device and network level that is lacking in traditional security approaches and technologies.

[0008] A significant metric that relates to the lack of remediation controls in current security controls is the high rate of false positives and negatives in the detection of threats. False positives are unproductive and reduce operating capacity in data centers. False negatives lead to the bypass of security controls and compromise of the target systems and services. Existing signature-based approaches to security control are vulnerable to improvised attacks staged at targeted systems.

[0009] The proliferation of applications (business, social networking and gaming software) in Enterprise and cloud computing ecosystems has significantly increased the attack surface and window of exposure. Application runtime operational integrity is a critical factor in building end-to-end trust from device to service. The proliferation of unmanaged devices such as mobile computing devices (i.e., tablets and smart phones) and Bring Your Own Device (BYOD) policies in Enterprise network environments has increased the risk of advanced coordinated threats.

[0010] The current predominant security paradigm is based on a hard edge and soft core architecture. Security appliances such as network firewalls and intrusion detection/prevention systems deploy at the edge (perimeter). Antivirus and network based integrity measurement and verification services scan and audit the soft-core that comprises business critical systems, services and high value data silos. Once the edge is breached, defensive methods are largely ineffective in protecting vulnerable or compromised systems. In this paradigm, the hard edge does not generally provide any level of assurance of the runtime operational integrity of the soft core.

[0011] The heavy reliance on extensive application whitelists/blacklists(based on file hash digests and/or configuration), Internet Protocol (IP) address reputation lists, signatures, protocol anomalies and virtual execution in a sandbox, provides targeted and coordinated attacks a large staging surface to maneuver around with meticulously engineered evasion methods exploiting the gaps. Irrespective of the method of break-in, the post-infection behaviors during the window of exposure on a victim machine or environment are difficult to conceal, but may be obscured from timely detection and diagnosis by security administrators and virtual execution (sandbox) environments through evasion techniques. Various exemplary embodiments include an early warning system for threat identification and diagnosis with high forensic confidence and infection summaries for manual and/or automated intervention.

[0012] Current identity management (IdM) approaches are typically aimed at domain level authentication of users for the use of a security token in a transaction or business process wherein the issuance of the token is strictly based on proof of possession of credentials and not the reputation of the user. While the industry has adopted multi-factor authentication technologies for increased protection from malicious users whose intent is to steal credentials for the purpose of impersonation or delegation, these security controls do not provide a means for incorporating attribution of an authenticated user's risk posture, independent of provisioned entitlements (i.e., user account privileges and roles). Thus, existing secu-

rity controls do not incorporate a complete view of a user's risk posture as a component of an access policy, based on correlation of location and device agnostic global threat intelligence about the user. Accordingly, what is needed are systems and methods for runtime operational integrity monitoring of applications by providing dynamic operational integrity attestation of application security and user reputation at runtime that take into account a subject's (such as a device, application, or user) risk posture. What is further needed are systems and methods for performing post infection diagnoses, threat identification via signature-less anomalous behavior recognition using non-intrusive platform instrumentation without requiring 'hooks' into an operating system (OS) Kernel by security vendors that leverages OS vendor application programming interfaces (APIs).

[0013] The emerging cloud based application-hosting model requires a higher level of scrutiny of device and user security posture. Threats can be posed by both external and internal users, and therefore it has become harder to determine whether an authenticated user is a trustworthy operative. Application and network layer entitlements are largely static in nature. While role based access control (RBAC) systems are positioned to offer dynamic policies, these are not based on any form of aggregation of external threat intelligence in the context of the user in the transaction.

[0014] Tokenization of identities by Security Token Services (STS) intended to facilitate in Identity Federation and Single Sign On (SSO) for web and Enterprise applications have only aggravated the threat vectors by expanding the scope of resources that an authenticated user may access implicitly without granular context. Along with the coarse access policies offered by traditional security controls, such as firewalls and intrusion prevention systems, this increases the attack surface for application exploits by malicious users leveraging the excessive privileges granted by default to most users (and groups) today, in the absence of strict Separation of Duties (SoD) and Principle of Least Privilege (PoLP) enforcement.

[0015] Several studies have uncovered conclusive evidence that the largest risk, associated with malicious activities resulting in theft of confidential data, intellectual property or financial losses for enterprises and consumers, arises from insider rather than outsider or man-in-the-middle attacks. Threat assessment systems have been predominantly focused on the means and methods rather than the adversary or operator (i.e., a user). There has been no emphasis on the reputation score of a user in the transaction or business process as a real time integrity metric for integration with access policy decision logic. Accordingly, what is further needed are systems and methods that employ a user reputation score that can serve either as a punitive or corrective method of intervention for the proactive prevention of exploits and data breaches.

[0016] One goal of trusted computing is to provide a resource owner or service provider with reliable knowledge about a target system. Current attestation systems are components of computer systems that permit reliable statements of evidence about those systems to be conveyed to remote parties, including other computers. Through evaluation of the identity and integrity of components of a system (i.e., a target system being evaluated), evidence is produced that the target system will not engage in defined classes of misbehaviors. As the users accessing a system and the requirements of applications running on a system generally cannot be known a priori, attestation systems and measurement systems alike must be flexible, providing for privacy, completeness of measurement, and trust in the basic collection and reporting mechanisms.

[0017] Existing attestation systems are often narrowly focused and generally aimed at specific use-cases limited to system components such as hardware and applications and therefore typically lack flexibility to dynamically address more general attestation problems. Further, existing definitions of attestation focus primarily on describing specific, narrow, and particular properties desirable in specific use-cases. Additionally, current attestation systems are created to work with one particular measurement system targeting one particular system of interest without considering the reputations of users or operators of the system of interest.

[0018] Accordingly, what the present inventors have identified as desirable are technology based attestation architectures, systems, and methods that perform a calculus of risk to determine a level of trust of systems that are not necessarily monolithic and can be made up of diverse hardware and software platforms and can be accessed by users with varying credentials and reputations. Accordingly, what the inventors have identified as being desirable are attestation architectures, systems, and methods that can be flexible enough to accommodate varying concepts of attestation, including taking the reputation of users that access targeted systems into account. What the present inventors also see as desirable are attestation systems and architectures that can dynamically handle complex attestation scenarios and provide more complete runtime attestation than is currently achievable. What the present inventors additionally see as desirable are methods and systems for performing evidence based automated application binary analysis.

SUMMARY OF THE DISCLOSURE

[0019] Exemplary methods and systems are disclosed for continuously monitoring one or more systems and/or to correlate events and behavior of systems on an instrumented target platform at runtime using or based on a plurality of assertions (or statements).

[0020] In exemplary embodiments, methods, apparatus, systems and computer readable media perform infection diagnosis based on reconnaissance based intelligence correlation and a threat life cycle model of advanced low-and-slow attacks wherein malware may operate through a series of benign actions at an endpoint device.

[0021] In other exemplary embodiments, methods, apparatuses, systems and computer readable media comprise a plurality of services that enable visibility, control, and/or compliance in a cloud computing environment with a runtime dashboard to capable of displaying operational integrity metrics of systems based on a plurality of threat vectors.

[0022] In yet other exemplary embodiments, methods, apparatuses, systems and computer readable media establish device-to-network flows based on dynamic attestation of device integrity, and/or security controls provisioned based on integrity and context aware business logic instead of, for example, topology based coordinates associated with encapsulation headers in network packets.

[0023] Exemplary systems and methods for dynamic attestation of application integrity are described in U.S. Non-Provisional patent application Ser. No. 13/399,065 entitled "System and Method for Application Attestation," filed Feb. 16, 2012, and U.S. Provisional Patent Application No. 61/443,854 entitled "System and Method for Application

Attestation," filed Feb. 17, 2011, both of which are incorporated herein by reference in their entireties.

[0024] According to exemplary embodiments, methods, apparatuses, systems and computer readable media authorize user-to-application transactions and/or data exchange in an established connection, during the authentication phase based on dynamic attestation of devices.

[0025] In accordance with further exemplary embodiments, methods, apparatuses, systems, and computer readable media determine a calculus of risk based on a plurality of sensory inputs from network and endpoint sensors to correlate network activity, system configuration, resource utilization and application integrity.

[0026] According to an exemplary embodiment, the network and endpoint sensors may be configured to measure runtime operational integrity and/or detect anomalous deviations in behavior from baseline based on rule sets to generate tiered alerts.

[0027] In accordance with exemplary embodiments, methods, apparatuses, systems and computer readable media comprise an event and behavior correlation engine configured to receive alerts, calculate risks and generate warnings.

[0028] In other exemplary embodiments, methods, apparatuses, systems and computer readable media remediate systems that are deviated, vulnerable, in duress or compromised based on a calculus of risk.

[0029] In accordance with yet other exemplary embodiments, methods, apparatuses, systems and computer readable media include: (1) a correlation engine configured to receive scan reports from vulnerability, configuration, compliance, and patch scan services; (2) a risk correlation matrix configured to store elements of the scan reports that are used to analyze the elements; and (3) a module configured to generate an integrity profile of systems.

[0030] The presently disclosed exemplary technical solutions also may be embodied as methods, apparatuses, systems and computer readable media comprising: (1) event correlation logic that correlates temporal system events based on multiple predicate scores; (2) logic to determine a predicate score based upon a deviation from a prescribed value constraint per attribute (or metric, i.e., an attribute constraint); (3) logic for calculating a score that is inversely proportional to the deviation; (4) logic for determining a sample rate needed to achieve a required measurement frequency; (5) logic for determining a recurrence of successive deviations; (6) logic for identifying a weight for the attribute constraint; (7) logic for determining an integrity confidence for the system or process (or application) entity as a weighted average of predicate scores; and (8) logic for determining identifying outliers as exceptions (across multiple systems or processes).

[0031] The exemplary methods, apparatuses, architectures, systems and computer readable media disclosed herein may also use threat identification categories including, but not limited to:

[0032] (1) static image analysis (i.e., static analysis of binary files, intermediate code, and/or scripts);

[0033] (2) dynamic image (binary, intermediate code, or script) analysis with process, platform and network monitors;

[0034] (3) malware analysis for evasion techniques (multiple packing, obfuscated application programming interfaces (APIs), anti-debugging, anti-memory, anti-tracing, virtual machine monitor/manager (VMM) or hypervisor/emulator detection;

[0035] (4) dynamic system analysis of performance metrics harvested through native machine instrumentation, registry, and file system monitors; and

[0036] (5) temporal system analysis with consolidated integrity measurement and verification assessments and scan reports.

[0037] The presently disclosed exemplary technical solutions may be embodied as a method, apparatus and/or system for integrity confidence measurement including: (1) a weighted average of system (or platform) predicate scores; (2) system (or platform) outliers; (3) weighted average of process (or application package) predicate scores; (4) process outliers.

[0038] The presently disclosed exemplary technical solutions also may be embodied methods, apparatuses, architectures, systems and computer readable media for generating user reputation scores for a plurality of users based on one or more of: (1) threat vectors modeled by actions of the plurality of users; (2) risk correlation with aggregation of intelligence related to accessed object (resource) attribution, subject roles, globally unique subject identifiers, security information and event management analytics, and geo-location services.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0039] The presently disclosed exemplary technical solutions are best understood from the following detailed description when read in connection with the accompanying drawings, to which the claimed invention is not limited. According to common practice, various features/elements of the drawings may not be drawn to scale. Common numerical references represent like features/elements. The following figures are included in the drawings:

[0040] FIG. **1** is an architecture diagram of an exemplary system for providing operational integrity attestation of application security and user reputation, according to an embodiment of the present disclosure;

[0041] FIG. **2** is a schematic diagram illustrating an exemplary system for endpoint and network activity correlation, according to an exemplary embodiment of the present disclosure;

[0042] FIG. **3**A is a flowchart illustrating steps by which early warning and response automation is performed through monitoring, orchestration and remediation, according to an exemplary embodiment of the present disclosure;

[0043] FIG. **3**B is a data flow diagram for intersystem risk assessment and remediation, according to an exemplary embodiment of the present disclosure;

[0044] FIG. **4** is a data flow diagram for configuring an attestation system by consolidating and normalizing network endpoint assessments, according to an exemplary embodiment of the present disclosure;

[0045] FIG. **5** illustrates communications between components of a system for measuring and evaluating application operational integrity, according to an exemplary embodiment of the present disclosure;

[0046] FIG. **6** is a block diagram illustrating data flows for instrumenting and measuring network endpoint risk, according to an exemplary embodiment of the present disclosure;

[0047] FIG. **7**A depicts exemplary endpoint events that can be monitored by the systems and methods disclosed herein;

[0048] FIG. **7**B depicts exemplary endpoint alerts that can be generated by the systems and methods disclosed herein;

[0049] FIG. **7**C is a block diagram illustrating a method for correlating endpoint alerts and generating endpoint warnings, according to an exemplary embodiment of the present disclosure;

[0050] FIG. **8** is a block diagram of a trust orchestration architecture for correlating a plurality of events for determining operational integrity of a system, according to an exemplary embodiment of the present disclosure;

[0051] FIG. **9** is a block diagram of a system for consolidating and correlating a plurality of identity, inventory and log management systems for determining a reputation of a user, according to an exemplary embodiment of the present disclosure;

[0052] FIG. **10** is a block diagram of a system for determining a calculus of risk, according to an exemplary embodiment of the present disclosure;

[0053] FIG. **11** is block diagram of a of a system for generating subject reputation scores based on a calculus of risk, according to an exemplary embodiment of the present disclosure;

[0054] FIG. **12** is a block diagram of a system for network flow remediation based on a calculus of risk, according to an exemplary embodiment of the present disclosure;

[0055] FIG. **13** a block diagram illustrating of a system for providing mobile security by remediating mobile devices and wireless network flows based on a calculus of risk, according to an exemplary embodiment of the present disclosure;

[0056] FIGS. **14-18** depict a graphical user interface (GUI) for an exemplary trust management console including dashboards for operational runtime integrity, system configuration, resource, application integrity, and network activity, in accordance with various exemplary embodiments;

[0057] FIGS. **19-22** are flowcharts illustrating methods for threat identification and remediation, providing a user reputation service, and providing network flow level remediation in accordance with various exemplary embodiments of the presently disclosed technology;

[0058] FIG. **23** is an entity-relationship diagram (ERD) illustrating relationships between entities of a reputation scoring system, according to an embodiment of the present disclosure;

[0059] FIG. **24** illustrates a hierarchical representation of a subject reputation score, according to an embodiment of the present disclosure;

[0060] FIG. **25** is a block diagram of an architecture for monitoring application events with extensions to native machine instrumentation, according to an exemplary embodiment of the present disclosure; and

[0061] FIG. **26** is a diagram of an example computer system in which embodiments can be implemented.

DETAILED DESCRIPTION

[0062] Although the invention is illustrated and described herein with reference to certain exemplary embodiments, the invention is not intended to be limited thereto. Rather, various modifications may be made that are within the scope and range of equivalents of the claims and without departing from the invention. Various features, attributes and advantages described herein may or may not be present in various embodiments of the claimed invention.

[0063] In the detailed description herein, references to "one embodiment," "an embodiment," "an example embodiment," etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0064] In certain exemplary embodiments, behavior deviations from a baseline healthy operational state to a vulnerable or compromised state may be detected, and the infection identified, before there is further propagation of the threat across interconnected systems, or information is exfiltrated resulting in data loss or theft.

[0065] The proliferation of unmanaged smart phones and Bring Your Own Device (BYOD) initiatives in the Enterprise ecosystem has increased the ability of advanced malware to evade traditional network and endpoint security controls and propagate to connected systems over standard protocols. Various exemplary embodiments include determination of the operational integrity of the device and/or the user in a transaction with an on-premise or off-premise service, based on the calculus of risk from a plurality of sensory inputs, for transaction and/or flow level remediation of infected devices.

Network for Monitoring and Dynamic Analysis of Events and Activities

[0066] FIG. **1** is an architecture diagram for an exemplary network **100** configured to continuously monitor and dynamically analyze events and network activity to ascertain the integrity of a monitored system (i.e., a target system).

[0067] Referring to the exemplary embodiment provided in FIG. **1**, the network **100** includes an event and behavior correlation engine **130** configured to perform risk correlation **120** based on continuous monitoring **110** using a plurality of sensory inputs. In the embodiment of FIG. **1**, the sensory inputs can include, but are not limited to, one or more of: network activity **111**; system configuration **113**; resource utilization **115**; and application integrity **117**. The network **100** also comprises a runtime dashboard **150** configured to receive real time status indications **131** for visibility of operational integrity of systems and a remediation engine **170** configured to receive real time directives **132** for control of infected systems.

[0068] The event and behavior correlation engine **130** is configured to receive network events and infection profiles **112** from a network activity sensor **111**, integrity measurement and verification reports **114** of scans performed by a system configuration sensor **113**. According to an embodiment, the scans are performed by the configuration sensor **113** according to a schedule. In embodiments, the scans can be scheduled to run daily, weekly, bi-weekly, monthly, or at other time increments as needed.

[0069] As shown in FIG. **1**, the event and behavior correlation engine **130** is also configured to receive endpoint events **116** of computing, network and storage resource consumption from a resource utilization sensor **115**, and endpoint events of image profiles and local execution context **118** from an application integrity sensor **117**. Details of exemplary implementations of the system configuration sensor **113**, the resource utilization sensor **115**, the application integrity sensor **117**, and the endpoint events **116**, **118** are described below with reference to FIGS. **4-7**.

[0070] The remediation engine **170** may perform actions **171** on a virtual machine (VM) **172**, actions **173** on a network flow controller **174**, or actions **175** on a transaction **176** based on configured trigger controls.

[0071] As will be appreciated by persons skilled in the relevant art(s), a VM is a software implementation of a machine such as a server, personal computer, mobile computing device, or other computing device that supports the execution of an operating system (OS) and executes applications as a physical machine running that OS would. A VM is a software implementation that duplicates the functionality of a physical machine implemented in hardware and software. Software applications and the OS running on a VM are limited to the resources and abstractions provided by the VM. Virtual machines (VMs) can be viewable within an overall virtual infrastructure. As will be appreciated by those skilled in the relevant art, a VMM or hypervisor can be used to start up, monitor, and manage VMs. Such hypervisors can be, but are not limited to VMMs such as the VMWARE™ Player, MICROSOFT™ VirtualPC, SUN™ VirtualBox, VMWARE™ ESX/ESXi, MICROSOFT™ Hyper-V, CITRIX™ XENServer, PARALLELS™ and others. As it would be apparent to one of skill in the art, other hypervisors and VMs/virtualization solutions can be used for VM **172** in network **100** as well.

Example System and Method for Endpoint and Network Activity Correlation

[0072] FIG. **2** is a schematic diagram illustrating an exemplary system **200** for endpoint and network activity correlation. In particular, the system **200** shown in FIG. **2** is configured to receive inputs for endpoint events, correlate the events, and generate outputs such as, but not limited to, warnings and reports.

[0073] As shown in FIG. **2**, the exemplary system **200** may include an endpoint event correlation module **240** configured to receive endpoint alerts **230** from an instrumented system **210** with a plurality of sensors configured to detect endpoint events related to one or more of application integrity **211**, resource utilization **212**, and system configuration **213**. The system **200** also comprises a network activity correlation module **260** configured to receive network alerts **250** from a network activity sensor **220**.

[0074] With continued reference to FIG. **2**, the network activity correlation module **260** is further configured to produce network warnings **270** resulting from the network activity correlation and output the network warnings **270** to an orchestrator **290**. The orchestrator **290** is configured to receive network warnings **270** from network activity correlation module **260** and endpoint warnings **280** from the endpoint event correlation module **240**. According to embodiments depicted in FIG. **2**, the received network warnings **270** and endpoint warnings **280** can be used by orchestrator **290** to coordinate manual or automated actions on infected systems.

[0075] With continued reference to FIG. **2**, the orchestrator **290** can similarly receive warnings produced by one or more additional instrumented systems (see, e.g., VM #N) with respective pluralities of sensors and endpoint event correlation modules.

[0076] As shown in FIG. **2**, the instrumented systems can include multiple virtual machines (VMs, i.e., VM **1** . . . VM #N) with respective pluralities of sensors configured to detect endpoint events related to one or more of application integrity **211**, resource utilization **212**, and system configuration **213**.

[0077] FIG. **3**A is a flowchart illustrating steps by which early warning and response automation is performed using monitoring, orchestration and remediation, in accordance with an exemplary method.

[0078] As shown in FIG. **3**A, an exemplary method **300** comprises receiving communications from an early warning system **301** configured to continuously monitor the runtime integrity of systems. This continuous monitoring enables near-real time determinations and detections of deviated, vulnerable, in duress, and compromised systems **307**.

[0079] The method **300** can operate in conjunction with legacy security technologies **305** to fill in the security holes or gaps inherent in traditional security solutions. As illustrated in FIG. **3**A, such legacy security technologies **305** can include anti-virus software, network firewalls, and intrusion detection/prevention systems (IDS/IPS). Unlike the early warning system **301** and the automated and rapid response **303**, the legacy security technologies **305** are limited to using signatures, detecting protocol anomalies or virtual execution in a sandbox to monitor threats and attacks. As shown in FIG. **3**A once a target of an attack or threat (i.e., a 'target system' or vulnerable system **307**) becomes infected or compromised, these technologies **305** can be ineffective in protecting the compromised/infected systems **307** and preventing data breaches or service disruptions.

[0080] Example limitations of legacy security technologies **305** are shown in FIG. **3**A. For example, as depicted in FIG. **3**A, a traditional network firewall technology **305** using access control lists (ACLs) cannot reliably block every threat. This is because firewalls are typically limited to monitoring well-known, default open ports used as listening ports for web protocols such as the Transmission Control Protocol/Internet Protocol (TCP/IP), email protocols such as the Simple Mail Transfer Protocol (SMTP) and the Post Office Protocol (POP), and other protocols such as the File Transfer Protocol (FTP), the Secret File Transfer Protocol (SSH), Secure FTP (SFTP), telnet, and the Remote Desktop Protocol (RDP). IDS and IDP technologies using rulesets cannot detect every zero-day signature/anomaly attack and have issues with regarding false negatives and leaving platforms/systems vulnerable to backdoor attacks. Similarly, anti-virus software cannot detect zero-day, mutant, and low-and-slow infections.

[0081] The method **300** can also supplement security audit scans **308** and manual IT process that may be in place. For example, an organization may periodically run security audit scans (i.e., on a weekly or bi-weekly basis). Such security audit scans may be National Institute of Standards and Technology (NIST)/Security Content Automation Protocol (SCAP) compliant checks for common vulnerability exposures to identify deviated and vulnerable systems **307**. The results from these scans may be used as part of manual IT processes for ticketing (i.e., creating 'trouble tickets' for deviated/vulnerable systems **307**) and security/compliance review boards. However, as shown in FIG. **3**A these manual processes triggered by merely periodic scans can takes days or weeks to react to threats, thus leaving target systems open to a long window of exposure.

[0082] The method **300** improves upon the legacy technologies **305**, periodic audit scans **308**, and manual IT processes **309** and makes up for their above-noted shortcomings by carrying out an automated and rapid response **303** for orchestration and remediation of infected systems **307**. In an embodiment, automated and rapid response **303** can be performed by monitoring and orchestration systems (not shown).

In the example of FIG. **3**, a protocol **302** is used for data exchange between the early warning system **301** and monitoring and orchestration systems.

[0083] In an embodiment, the early warning system **301** monitors instrumented systems to measure and evaluate runtime operational integrity to determine whether a system **307** has deviated, become vulnerable, is in duress or has been compromised. Once this determination has been made, the system **307** is marked by the early warning system **301** as one or more of a deviated system, a vulnerable system, an in duress system, or a compromised/infected system. The early warning system **301** can then issue warnings regarding the system **307** via the protocol **302** so that an automated and rapid response **303** can be carried out by monitoring and orchestration systems.

[0084] FIG. **3**B is a schematic diagram illustrating an exemplary method **310** for determining a calculus of risk, in accordance with exemplary embodiments.

[0085] Referring to FIG. **3**B, the exemplary method **310** may include determining or performing a calculus of risk **320** for the data center application and data silos, that receives sensory inputs **314** from instrumentation **313** including integrity measurement and verification scan correlation **315**, network activity correlation **316** and endpoint event correlation **317**, and may generate integrity metrics for security orchestration **321**, and may dispatch directives to an edge device **323** (for example, network firewall) for user access controls **322**, to a load balancer **325** for session controls **324**, or to a network fabric element **327** (for example, a switch or router) for flow controls **326**.

[0086] With continued reference to FIG. **3**B, the security orchestration **321** may include user access controls **322** as a remediation or mitigation means to block the infected device or malicious user from accessing protected data center centers, session controls **324** to divert users from infected systems or infected devices from protected systems, flow controls **326** to quarantine infected systems, divert traffic away from protected systems, or redirect traffic from attackers to pure, high-interaction or low-interaction honeypots.

[0087] FIG. **4** illustrates data flows used to configure an attestation system. In particular, FIG. **4** depicts a data flow for consolidating and normalizing network endpoint assessments as part of a configuration for an exemplary attestation system **400**.

[0088] Referring to FIG. **4**, the exemplary attestation system **400** includes a trust orchestrator **430**, a trust broker **407** configured to receive integrity reports **406** published by endpoint assessment services **401**.

[0089] Trust Broker and Integrity Report

[0090] With continued reference to FIG. **4**, the trust broker **407** can be configured to receive sensory data feeds that represent the configuration state of the system based on a remotely administered scan of a device, such as device **560** described with reference to FIG. **5** below, by endpoint assessment services **401**. These scans provide a snapshot in time of the state of the system and are agnostic to runtime aspects of the system including applications thereon.

[0091] In an embodiment, the sensory data is represented in a markup language such as, but not limited to, Extensible Markup Language (XML). An integrity report **406** includes this sensory data. In embodiments, the integrity report **406** is generated by third party endpoint assessment services at platform- and application-level granularities. According to embodiments, the integrity report **406** may be received by the trust broker **407** either: (a) programmatically through outbound application programming interfaces (APIs) provided by respective application vendors; or (b) manually through importing the integrity report **406** as a file provided by an administrator through a dashboard of an administrative console user interface (UI) in a specified file format. Examples of an administrative console UI are discussed below with reference to FIGS. **14-18**.

[0092] The trust broker **407** can also be configured to parse, normalize and collate received integrity reports **406**. In accordance with embodiments, the parsing, normalizing, and/or collating can be based on one or more object identifiers. Exemplary object identifiers can include, but are not limited to, machine hostnames, IP addresses, application names, and package names. This parsing, normalization, and collation (collectively, processing) generates temporal events **409** that annotate the state of the endpoints (devices) at scan time. Additional embodiments of the trust broker are described with reference to FIGS. **5**, **9**, and **11** below.

Temporal Events

[0093] According to embodiments, the temporal events **409** can be expressed as assertions about operational parameters (e.g., vulnerabilities, compliance, patch level, etc.) based on enterprise policies established for a baseline configuration. The trust broker **407** serves as a moderator that aggregates endpoint operational state measurements for situation awareness and threat identification by the trust orchestrator **430**.

[0094] With continued reference to FIG. **4**, the temporal events **409** can be an annotation (e.g., an XML representation) of the configuration state of the system (including device, application and package) and include trust and severity scores as generated by third party security vendors based on integrity measurement and verification, in accordance with standards established by organizations. These organizations can include NIST, the MITRE Corporation, and the United States Computer Emergency Readiness Team (US-CERT). The temporal events can be assertions about operational parameters expressed in the Open Vulnerability and Assessment Language (OVAL) to convey system details representing configuration information and a system/machine state including vulnerability, configuration, patch level, etc. Alternatively, the system details can be conveyed using the SCAP protocol. According to embodiments, the state representation includes schema attributes to measure configuration, vulnerability (exposures), compliance, and patch level based on severity. Compliance can be expressed in terms of the Extensible Configuration Checklist Description Format (XCCDF) using XCCDF checklists for devices attached to a system's Peripheral Component Interconnect (PCI) bus, and data security/system integrity compliance with the Health Insurance Portability and Accountability Act (HIPAA), Sarbanes-Oxley Act (SOX), and/or the Gramm-Leach-Bliley Act (GLBA).

[0095] As shown in FIG. **4**, the integrity reports **406** can be generated by performing one or more scans, including, but not limited to, a vulnerability scan **402**, a configuration scan **403**, a compliance scan **404**, and a patch scan **405** of networked endpoints. In an embodiment, the trust broker **407** can be implemented as the Trust-as-a-Service (TaaS) Broker from TAASERA, Inc. In one exemplary embodiment, the trust orchestrator **430** can be implemented as the TaaS Orchestrator from TAASERA, Inc.

[0096] With continued reference to FIG. **4**, the attestation system **400** further comprises a normalizer and collator **408** and a system event correlator **410** configured to receive temporal events **409** associated with an endpoint and use a risk correlation matrix **411** to correlate and generate an integrity profile **420** for an endpoint. According to embodiments, the system event correlator **410** shown in FIG. **4** can be configured to receive temporal events **409** generated by the trust broker **407** that measure the integrity of the system at last scan. Additional exemplary features of the system event correlator **410** are described below with reference to FIG. **5**.

[0097] Integrity Profile

[0098] In the embodiments of FIGS. **4-6**, the integrity profile **420** represents an aggregation of system warnings (threats such as malware) identified based on the received temporal **409** and endpoint **520** events. In one embodiment, the format (schema) of the integrity profile **420** is a standard Extensible Markup Language (XML) notation.

[0099] Risk Correlation Matrix

[0100] In embodiments, the risk correlation matrix **411** depicted in FIGS. **4-6** and the risk correlation matrix **721** described with reference to **7**A-**7**C are embodied as grids that represent an exemplary dynamic model of measurement and identification based on clustering and classification of independent endpoint events (alerts) to generate system warnings that may be mapped to warning categories or classes. Additional details of the risk correlation matrices **411** and **721** are provided below with reference to FIGS. **6**, **7**B, and **7**C.

System for Evaluating Operational Integrity of Applications

[0101] FIG. **5** illustrates communications between components of a system **500** for measuring and evaluating application operational integrity. In particular, FIG. **5** depicts communications between components of the application operational integrity system **500** used to evaluate application integrity based upon executable image profiles and process monitoring, and evaluate resource utilization based upon process and system monitoring. In embodiments, image profiles are generated for executable images such as, but not limited to, binary images, intermediate images, or scripts. FIG. **5** is described with continued reference to the embodiment illustrated in FIG. **4**. However, FIG. **5** is not limited to that embodiment.

[0102] As shown in FIG. **5**, the exemplary application operational integrity system **500** includes an endpoint trust agent **510** on a device **560** comprising a process monitor **514** configured to observe local execution context of applications and services. The endpoint trust agent **510** further comprises a socket monitor **513** configured to observe network activities of applications and services and a system monitor **512** configured to observe system and platform resources consumed by applications and services. In the example embodiment provided in FIG. **5**, the trust agent **510** also comprises an application integrity module **516** and a resource utilization module **515** configured to assess operational integrity based on rulesets. The trust agent **510** can also comprise native machine instrumentation **511** for a computing device being monitored by the application operational integrity system **500**.

[0103] Device

[0104] In embodiments, the device **560** depicted in FIG. **5** may be a desktop, server, laptop, a mobile computing device such as a smart phone or tablet, or other types of mobile computing platforms that comprise (a) an operating system (OS); (b) a user operating the device to access a service or another device **560** over a network; and (c) application packages, applications or application components that may be downloaded and installed either with or without user intervention for later execution. Non-limiting examples of the device **560** include a personal computer, server, laptop, or tablet device running a MICROSOFT™ WINDOWS® operating system (OS), a personal computer, server, or laptop running an OSX OS from Apple Inc., a personal computer, server, or laptop running a UNIX or Linux OS, a personal digital assistant (PDA), an iPhone™, an iPod™ touch, or iPad™ tablet device running an iOS from Apple Inc., a device operating the Android OS from Google Inc., device running the MICROSOFT™ WINDOWS® Mobile or Phone OS, a device running a Symbian OS, a device running a PALM OS®, a BLACKBERRY® device running a Blackberry OS from Research In Motion ("RIM"), a mobile phone, a portable game device, a gaming console, a hand held computer, a netbook computer, a palmtop computer, an ultra-mobile PC, or another similar type of computing device capable of processing instructions and receiving and transmitting data to and from users and other computing devices.

[0105] Native Machine Instrumentation

[0106] In embodiments, the native machine instrumentation **511** can represent any event subscription, callback, notification mechanism provided by the supported operating system (OS) on the device **560** (e.g., MICROSOFT™ WINDOWS® Machine Instrumentation (WMI), Transport Filter Drivers, Application Layer Enforcement Callout Drivers, Linux/Unix Network Filter Drivers, etc.). The native machine instrumentation **511** can generate raw events, as described below with reference to the illustrative example in FIG. **7**A, that may appear insignificant as an isolated occurrence, but may include notable data points as forensic evidence of behavior anomalies or malicious activity to the event and risk correlation system.

[0107] Referring to FIG. **5**, the trust broker **407** can be configured to receive one or more state attributes pertaining to applications running on a device **560** and components from the endpoint trust agent **510**. The trust broker **407** serves as an arbitrator configured to dispatch a request for image analysis to one or more third party malware analyzers **540**. In one embodiment, the dispatch mechanism uses trigger filter expressions that specify the set of criteria that warrant initiation of image analysis (e.g., frequency and volume of requests for analysis associated with the image across deployed endpoint trust agents), and parameters configured for each available connector to a third party malware analyzer **540**. According to an embodiment, the parameters include cost, latency, and platform specific analysis capabilities. Such platform specific analysis capabilities can include static and dynamic analysis of applications on mobile platforms such as, but not limited to, devices **560** running an Android operating system (OS) from Google Inc., a PALM OS®, a MICROSOFT™ WINDOWS® Mobile or Phone OS, a Symbian OS, a Blackberry OS from Research In Motion (i.e., a BLACKBERRY® device **560**), or an iOS (i.e., iPhone™, an iPod™ touch, or iPad™ devices **560**).

[0108] The third party malware analyzers **540** perform static and dynamic analysis of the application images based on policies specified by the trust broker. The result of the malware analysis is a set of threats identified based on the analysis. The trust broker caches the results of the analysis indexed by a unique identifier for the image. The trust broker

generates and returns an image profile **519** to the endpoint trust agent **510** which comprises assertions of malicious capabilities of the image that must be monitored at runtime for subsequent generation of endpoint events **520** by the endpoint trust agent **510**.

[0109] Endpoint Events

[0110] In the embodiment shown in FIG. **5**, the endpoint events **520** are generated by a component of the endpoint trust agent **510**, and represent alerts based an endpoint sensor resident on the device **560**. The alerts are mapped to a cell in the risk correlation matrix **411** grid by the system event correlator **410**. In one embodiment, the format (schema) of the endpoint events **520** is a standard Extensible Markup Language (XML) notation. Additional features of the endpoint events **520** are described below with reference to FIG. **6**

[0111] With continued reference to FIG. **5**, the application operational integrity system **500** can include a trust orchestrator **430** comprising a system event correlator **410** and a trust broker **407**. The application operational integrity system **500** can further include a malware analyzer **540**. In an embodiment, the trust orchestrator **430** can be implemented as the TaaS Orchestrator from TAASERA, Inc.

[0112] According to the exemplary embodiment depicted in FIG. **5**, the system event correlator **410** can be configured to receive endpoint events **520** from the endpoint trust agent **510** as sensory inputs to a calculus of risk. The trust broker **407** is configured to receive an image file and image attributes **518** and then send the received image file to the malware analyzer **540** for diagnosis. The trust broker can also receive an asynchronous prognosis **533** and forward an asynchronous image profile **519** to the process monitor **514** to include in ruleset processing for diagnosis at the application integrity module **516**.

[0113] System Event Correlator

[0114] According to embodiments, the system event correlator **410** shown in FIG. **5** can be configured to receive temporal events **409** generated by the trust broker **407** that measure the integrity of the system at last scan, and endpoint events **520** from the endpoint trust agent **510** that measure the runtime execution state of applications. The system event correlator **410** can be further configured to map the events to a cell in the risk correlation matrix **411** grid and processes the triggered system warnings to evaluate threats by category (or vectors). In one embodiment, the categories include at least resource utilization, system configuration, and application integrity. Each category is assigned a metric that is an indicator of the level of runtime operational integrity that may be asserted based on the system warnings and threat classification produced by the risk correlation matrix **411**. The system event correlator **410** can also be configured to generate an integrity profile **420** for the device **560** that describes the security risks and threats posed by the measured execution state of running applications on the device **560**.

[0115] FIG. **6** depicts data flows between components of an exemplary system for correlating endpoint events. In particular, FIG. **6** illustrates data flows between components and modules of a system event correlation system **600**. FIG. **6** is described with continued reference to the embodiments illustrated in FIGS. **4** and **5**. However, FIG. **6** is not limited to those embodiments.

[0116] Referring to FIG. **6**, the exemplary correlation system **600** includes an endpoint trust agent **510** on a device **560** that comprises runtime monitor **620** configured to register for and receive a plurality of raw events **611** from native machine instrumentation **511** on the device **560**. The runtime monitor **620** is further configured to raise integrity events **621** to an integrity processor **630** that may apply rulesets **631** to generate integrity alerts **632** and generate or populate an event correlation matrix **633** that maps integrity warnings **634** to endpoint events **520** for dispatch to a trust orchestrator **430**.

[0117] In the embodiments shown in FIGS. **6** and **7**A-**7**C, the endpoint events **520** are generated by the integrity processor **630**, which is a component of the endpoint trust agent **510**, and represent alerts based an endpoint sensor resident on the device **560**. As described above with reference to FIG. **5**, the alerts can then be mapped to a cell in the risk correlation matrix **411** grid by the system event correlator **410**, which can be configured to read endpoint events **520** expressed in XML notation.

[0118] With continued reference to the exemplary embodiment provided in FIG. **6**, the trust orchestrator **430** comprises a system event correlator **410** configured to use a risk correlation matrix **411** to generate an integrity profile **420** for the monitored system (i.e., the target system). In one embodiment, the system event correlator **410** can be implemented as a correlation engine. In another embodiment, the trust orchestrator **430** can be implemented as the TaaS Orchestrator from TAASERA, Inc.

[0119] For the risk correlation matrix **411** shown in FIG. **6**, each cell in the grid is a set of alerts triggered through an event correlation matrix **633** and rulesets **631** (rule expressions) by the endpoint trust agent **510**.

[0120] In certain exemplary embodiments, the application integrity module **516** and the resource utilization module **515** described above with reference to FIG. **5** may be included as a subcomponent or module of the integrity processor **630** depicted in FIG. **6**.

[0121] In certain exemplary embodiments, the process monitor **514**, system monitor **512** and socket monitor **513** depicted in FIG. **5** and described above may be included as subcomponents or modules of the runtime monitor **620**.

[0122] FIG. **7**A is a diagram indicating groupings of exemplary endpoint events **700** that can be monitored and analyzed by the presently disclosed methods and systems to determine a system integrity profile. In particular, the endpoint events **700** shown in FIG. **7**A can be used to determine what an attestation system can assert about the integrity of a monitored system (i.e., a target system). FIG. **7**A is described with continued reference to the embodiments illustrated in FIGS. **1**, **4**, **5**, and **6**. However, FIG. **7**A is not limited to those embodiments.

[0123] By continuously monitoring for the endpoint events **700** and performing dynamic analysis of detected endpoint events **700**, assertions about the integrity of a target system can be made. For example, the endpoint events **700** can be included in the endpoint events **116**, **118** received by the event and behavior correlation engine **130** in the network **100** described above with reference to FIG. **1**.

[0124] In one embodiment, one or more of the endpoint events **700** can be included in the endpoint events **520** used by the attestation system **500**, described above with reference to FIG. **5**. In other embodiments, the endpoint events **700** can be included in the endpoint events **520** used by the system event correlator **410** of the correlation system **600** depicted in FIG. **6**.

[0125] Referring to FIG. **7**A, the exemplary endpoint events **700** may include per process events **701**, per processor events **702**, system events **703**, and per image binary analysis

events **704**. According to an embodiment, the events **701-704** can include, but are not limited to, all events available through native machine instrumentation and extensible on the platform with provider plug-ins.

[0126] FIG. **7**B is a block diagram **710** illustrating exemplary alerts that can be generated by the methods and systems discussed herein.

[0127] As shown in FIG. **7**B, in embodiments, alerts may include platform alerts **711**, per image alerts **712**, grayware alerts **713** (i.e., for a watch list), and per application alerts **714**. The alerts are configurable and extensible, and not limited to the alerts illustrated in FIG. **7**B.

[0128] FIG. **7**C is a block diagram illustrating an exemplary method **720** for correlating endpoint alerts and generating endpoint warnings using a correlation matrix. FIG. **7**C is described with continued reference to the embodiments illustrated in FIGS. **4-6**. However, FIG. **7**C is not limited to those embodiments.

[0129] Referring to FIG. **7**C, the method **720** populates a risk correlation matrix **721** based upon one or more of system warning classes **722**, system warnings **723**, and integrity warnings **724**. As shown in FIG. **7**C, an alert expression can be expressed as a function **725** of at least an attribute, an attribute value constraint, a sample rate, a recurrence, a score and a weight. The function may be specified in any programming language or construct, as compiled, intermediate or interpreted code.

[0130] The risk correlation matrix **721** can comprise a universally unique identifier (UUID) for the system, system warnings **723** mapped to at least one system warning class **722**, and at least a system warning class **722** to diagnose system deviations (i.e., system deviated integrity warnings **724**), system duress, system vulnerable and system infections (i.e., system infected integrity warnings **724**).

[0131] In the embodiment of FIG. **7**C, each alert for the risk correlation matrix **721** is generated by a program function **725** that evaluates expressions that are specific for each attribute of the device **560**. Based on the occurrence of a qualifying set of alerts in each cell, the corresponding system warning is triggered. In FIG. **7**C, the exemplary risk correlation matrix **721** illustrates that for each device **560** (or application) uniquely identified by a machine identifier (e.g., a virtual machine universally unique identifier (UUID), IP address) or application instance identifier (application UUID), a different set of alerts may trigger different system warnings that map to a common system warning class. By mapping alerts to a behavior model (or cluster), unknown (such as emerging or polymorphic) threats may be classified and identified without requiring image or wire level signatures. The alerts may be grouped as illustrated in FIG. **7**B to represent a category of alerts (e.g., platform, application, grayware—that includes applications that are placed on a watch list based on reports generated by third party malware analyzers, image—that are weighted by threat level based on inspections performed by the endpoint trust agent **510** or malware analyzers **540**). In an embodiment, the program function **725** can be configured to use conditional expressions (operators) to generate an alert based on value constraints, sample rate for the measurement, recurrence of measured values, an assigned score and weight for the attribute. According to embodiments, the score and weight can be predefined or customizable through a graphical user interface GUI or dashboard, such as the GUIs described below with reference to FIGS. **14-18**.

[0132] In accordance with embodiments, a plurality of timers may be associated in the evaluation of system warnings and system warning classes, the calculus of risk, and generation of an integrity profile for the system.

[0133] According to embodiments, the integrity profile **420** comprises at least the endpoint address and one or more of system warning class, forensic confidence of the declared warning, and the full evidence chain.

[0134] Integrity Processor

[0135] With reference to FIGS. **6** and **7**A-**7**C, the integrity processor **630** is a functional component of the endpoint trust agent **510**. The integrity processor **630** can be configured to receive integrity events **621** from the runtime monitor **620** that describes process, processor, system and binary analysis events illustrated in FIG. **7**A. Applying qualifying rule expressions (illustrated in FIG. **7**B) in the rulesets **631**, integrity alerts **632** are generated and mapped to a cell in an event correlation matrix grid **633** (analogous to the risk correlation matrix **411** of FIG. **4** and grid **721** of FIG. **7**C) to generate system level integrity warnings **634**. The rows in the event correlation matrix **633** represent an application instance on the device **560** (analogous to rows in the risk correlation matrix **411** that represent a device by machine identifier). The integrity warnings **634** can be formatted as endpoint events **520** for dispatch to the system event correlator **410** of the trust orchestrator **430** for threat classification and identification and subsequent remediation.

[0136] In accordance with embodiments, a plurality of alerts **711-714** in a variety of user configurable combinations (for example, as editable settings in an XML or text format configuration file, or through a graphical administrative dashboard or user interface) constitute a system warning, and a system warning maps to a system warning class.

[0137] In accordance with embodiments, a plurality of system warning classes can be included in the integrity profiles **420** of the attestation system **400** and correlation system **600** depicted in FIGS. **4** and **6** respectively.

Example Trust Orchestration Architecture

[0138] FIG. **8** is a block diagram of an exemplary architecture **800** for trust orchestration including a trust orchestrator **430**, a network analyzer **830**, and a device **560**. The architecture **800** can be used to correlate a plurality of events for determining runtime operational integrity of a system. FIG. **8** is described with continued reference to the embodiments illustrated in FIGS. **4**, **5**, and **7**C and with reference to FIGS. **12** and **13**. However, FIG. **8** is not limited to those embodiments.

[0139] As shown in FIG. **8**, the trust orchestration architecture **800** may include an endpoint trust agent **510** on a device **560**, a network analyzer **830** that may include a network activity correlator **831**, an endpoint assessment service **820**, a service provider for orchestration and/or policy enforcement point services **860**, and a trust orchestrator **430** that may include a trust broker **407**, a system event correlator **410**, a trust supervisor **846**, and a remediation controller **848**.

Trust Orchestrator

[0140] According to the embodiments of FIGS. **4** and **8**, the trust orchestrator **430** is an aggregation that includes functional components such as the trust broker **407**, system event correlator **410**, the trust supervisor **846**, and remediation controller **848**. In embodiments, the trust orchestrator **430** is

configured to receive sensory threat intelligence from network analyzers **830**, endpoint assessment services **820** and endpoint trust agents **510** on devices **560**. Through a sequence of normalization, collation and risk correlation of events, directives **849** in the form of directives are dispatched to orchestration services to initiate remediation actions to deal with identified threats on devices **560**. The directives are specific to the orchestration service and can include the use of vendor APIs. Examples of such vendor APIs include VMWARE™ vCloud APIs, BMC Atrium™ APIs for accessing a BMC Atrium™ configuration management database (CMDB) from BMC Software, Inc., Hewlett Packard Software Operations Orchestration (HP-OO) APIs, and standard protocols such as Open Flow.

[0141] In certain exemplary embodiments, the system event correlator **410** receives endpoint events **520** from the endpoint trust agent **510**, temporal events **409** from the trust broker **407**, correlates and sends an integrity profile for a network endpoint to the trust supervisor **846** and the network activity correlator **831**.

[0142] In certain exemplary embodiments, the trust supervisor **848** receives an infection profile **832** for a network endpoint from the network activity correlator **831**, an integrity profile **420** for a network endpoint from the system event correlator **410**, analyzes and classifies threats along with a forensic confidence score, sends real time actions **847** to the remediation controller **848**, and real time status indications **850** to a dashboard controller **870**. The remediation controller **848** sends directives **849** to orchestration and/or policy enforcement point services **860** for machine, flow or transaction level remediation.

[0143] Remediation Controller

[0144] In embodiments, the remediation controller **848** can be configured to receive action requests **847** from the trust supervisor **846**. The remediation controller **848** can also be configured to process the received requests and perform appropriate operations on orchestration services. According to embodiments, upon processing a received action request the remediation controller **848** may perform (a) a flow level operation on a network element **1216** (e.g., a physical or virtual switch or a firewall) or wireless access point **1320**; (b) a machine level operation on a device **560** (e.g., a web or database server); (c) a transaction level operation to restrict access to a service or device **560**; and/or (d) an update notification to a network trust agent (see, e.g., network trust agents **1209** and **1315** depicted in FIGS. **12** and **13**, respectively) to indicate a revised reputation score for a device **560**.

[0145] In embodiments, the infection profile **832** comprises at least the victim endpoint address and one or more of a forensic confidence of the declared infection, the attacker source, the command and control source, the full evidence chain, and the infection time range (onset, duration).

[0146] According to embodiments, the integrity profile **420** comprises at least the endpoint address and one or more of system warning class, forensic confidence of the declared warning, and the full evidence chain.

[0147] In accordance with embodiments, the risk correlation matrices **411** and **721** of FIGS. **4** and **7**C, respectively, may be included in the trust supervisor **846** to consolidate and correlate integrity profile **420** and infection profile **832** of FIG. **8**.

Example Threat Detection and Mitigation Scenario

[0148] An exemplary flow of a threat detection and mitigation sequence is described below with reference to FIGS. **3**A, **4**-**6**, **7**B, **8**, **10**, **12**, **13**, and **23**. In the example scenario below, the exemplary threat is a user device infected with malware. The paragraphs below detail how exemplary embodiments described herein with reference to FIGS. **4**-**6**, **7**B, **8**, **10**, **12** and **13** can handle such 'real world' threat vectors. The multi-dimensional event and risk correlation model described in the following paragraphs illustrates an exemplary method of detecting low and slow signature-less threats that are characteristic of emerging malware and advanced persistent threats.

[0149] A user's (**1014**) device D (**560**) may become infected with a form of an advanced persistent threat (e.g., malware $M_{(benign)}$) while he device D is still connected to an enterprise network of an organization **2303**. The connection of the device D to the enterprise network can occur through user activity, for example, when the user **1014** connects a plug-and-play portable universal serial bus (USB) device with the malware $M_{(benign)}$ to the device D while it is connected to the enterprise network, as the result of the user **1014** opening an email attachment infected with the malware $M_{(benign)}$, when the user **1014** accesses a social network application from the device D, or when the user **1014** unwittingly transfers a file with the malware $M_{(benign)}$ to device D while accessing a file sharing service.

[0150] The device D can also become infected with malware $M_{(benign)}$ while the device D is disconnected from the enterprise network of the organization **2303**. For example, the device D can become infected as a result of user activity on a home network, or external wireless or wired network not managed by an enterprise IT administrator of the organization **2303**, such as a mobile network or the Internet.

[0151] Once the device D is infected, an egg download (i.e., download of an .egg compressed archive file) that evaded traditional network edge protections (e.g., legacy security technologies **305** such as firewalls and network IPS/IDS systems) has occurred. At this stage of infection, legacy security technologies **305** such as traditional antivirus programs installed on the device D are unlikely to detect the targeted malware $M_{(benign)}$ because no signature or blacklist already exists for this threat. The malware $M_{(benign)}$ may then perform discrete (and apparently benign) surveillance operations on the device D, such as periodic process restarts, executable file property modifications (i.e., changes to file name and/or size attributes) to introduce entropy and evade detection. The malware $M_{(benign)}$ may also make registry modifications, perform keyboard/input device monitoring, screen level monitoring, memory dumps, disk navigation to inspect files without excessive resource (CPU) utilization on the device D.

[0152] At this post-infection stage, the endpoint trust agent **510** monitors the executing malware process $P_{(benign)}$, performs file and component (e.g., dynamic link library(DLL)) level integrity checks including checking a file hash digest, digital signature, and certificate chain verification by leveraging collaboration services, such as the collaboration services **1207** and **1312**, described below with reference to FIGS. **12** and **13**, respectively, to access intelligent whitelisting services. These collaboration services are accessed through the trust orchestrator **430**. Failure of one or more of these checks immediately places process $P_{(benign)}$ on a grayware alert **713** (i.e., a watch list).

[0153] Assuming no checks fail at this stage, the process $P_{(benign)}$ is continuously monitored by the integrity processor

630 for explicit rule violations. In an embodiment, violations of a rule in a ruleset **631** are continuously monitored for and detected. These rules detect anomalous behaviors in benign processes. Once a rule trigger criteria is reached, the endpoint trust agent **410** initiates an image integrity check and leverages a remote malware analyzer **540** through the trust orchestrator **430**. The purpose of this check is to avoid complete reliance on supply chain provenance and locally available evidence. The image profile **519** generated from malware binary analysis provides the integrity processor additional local events to monitor for process $P_{(suspect)}$.

[0154] At this point, the malware analyzer **540** reports capabilities detected (present in reverse engineered code) through static and dynamic analysis of the image. Such image analysis can look for code obfuscation techniques in the reverse engineered code such as anti-debug, anti-trace, anti-memory, and anti-emulation, use of network communication protocols like SMTP, FTP or HTTP, use of embedded uniform resource locators (URLs) or IP addresses, use of encryption methods such as use of the secure sockets layer (SSL) protocol, listening on local ports, remote ports accessed, file system operations, registry operations, operations in temporary, system or non-program folders, memory peek or poke operations, and remote thread creation.

[0155] The integrity processor **630** then monitors process $P_{(suspect)}$ for related warnings **721** and triggers endpoint events such as alerts **711-714** to the system event correlator **410**. Multiple endpoint assessment services **820** may be deployed in the enterprise network to perform scheduled policy based scans to detect known exposures (vulnerability, configuration, compliance and patch level exploits). The respective integrity reports **821** may contain indications of exposures on the device D. However, these reports do not affirm positive presence of a threat or an infection on the device D and may be unaware of the existence and runtime activities of process $P_{(suspect)}$. The trust broker **407** generates temporal events **409** that inform the system event correlator **410** of the damage potential (severity) on the device D should any malicious program be active on the device (e.g., a personally identifiable information (PII) violation on a database server, a buffer overflow attack on an application server, a structured query language (SQL) injection attack on a database server, a keystroke or screen element capture, a microphone or camera hijack, etc.) based on authoritative state (snapshot) information and scan policies applied in the assessment of device D.

[0156] Based on risk analysis triggered by endpoint and temporal events, an integrity profile is generated by the system event correlator **410** for the device D. The network activity correlator **831** concurrently monitors all network traffic and activities of device D and dispatches infection profiles **832** based on forensic evidence of malicious network dialogs indicative of an infected victim (device D). The evidence may be indicative of malicious activities such as peer-to-peer propagation, command and control communications, or data exfiltration to an attacker. The trust supervisor **846** classifies the forensic evidence based on the integrity and infection profiles generated independently by the endpoint, network, and scan based assessment sensors to determine the threat risk level of the device D with high forensic confidence to warrant an immediate manual or automated remediation action to mitigate the detected infection.

System for Integrity Profile Generation

[0157] FIG. **9** is block diagram illustrating an exemplary system for generating a subject integrity profile. The system **900** shown in FIG. **9** can be used to consolidate and correlate a plurality of identity, inventory and log management systems in order to determine a reputation of a subject (e.g., a user, device, transaction, service, or organization/company). FIG. **9** is described with continued reference to the embodiments illustrated in FIGS. **4** and **5**. However, FIG. **9** is not limited to those embodiments.

[0158] Referring to FIG. **9**, the exemplary subject integrity profile system **900** includes a trust orchestrator **430**, a trust broker **407** that can be configured to query and receive an associated response **905** from a plurality of management systems.

[0159] With continued reference to FIG. **9**, the integrity profile system **900** can include a plurality of subsystems, including an inventory management system **901** configured to provide resource object attributes, a role management system **902** configured to provide subject (or user) attributes (e.g., roles and entitlements), an identity management system **903** configured to provide aggregated subject attributes, a log management system **904** configured to provide information and events categorized by subject, a system event correlator **410** that receives temporal events **409** categorized by subject, and a risk correlation matrix to generate an integrity profile **420** for a subject that comprises a unique subject identifier and a reputation score.

[0160] Within the context of the subject integrity profile system **900**, the trust broker **407** is configured to query and receive responses from third party management systems regarding inventory, role, identity and logs.

Inventory Management System

[0161] The inventory management system **901** shown in FIG. **9** is configured to provide information pertinent to devices **560** (e.g., mobile devices **560**, mobile applications, enterprise desktops, servers, etc.). Examples of inventory management systems **901** include commercial products available from the IBM and Oracle Corporations used for managing an inventory of Enterprise IT managed assets.

[0162] Role Management System

[0163] According to embodiments, the role management systems **902** shown in FIG. **9** can be configured to provide information pertinent to a user's organizational roles, resource level privileges, application level entitlements, and extended group memberships (i.e., project level privileges and roles). Examples of role management systems include commercial products available from Oracle, Computer Associates, IBM, and SAP for role based access controls to database objects, files, servers, directories/folders, web servers, applications, network domains/subdomains, printers, and other resources. In some of these systems, users are assigned one or more roles that aggregate a set of privileges and permissions. For example, roles in an Oracle or IBM relational database environment represent different tiers or levels of access to database objects. For example, a user account with a 'database administrator' (DBA) role may have privileges and permissions needed to delete (i.e., drop), create, and alter database objects such as tables, views, synonyms, stored procedures, triggers, user accounts, entire databases, and other roles. In contrast user accounts with lesser roles, such as a developer or user role may only be able to insert and update

data in database tables and views and revise existing stored procedure and trigger code. Yet other roles may be restricted to 'read only' access to select records from database tables and views as needed to generate reports and run queries.

[0164] Identity Management System

[0165] In accordance with embodiments, the identity management systems **903** shown in FIG. **9** can be configured to provide information pertinent to a user's organizational domain accounts and group level memberships (e.g., MICROSOFT™ Active Directory, Oracle Internet Identity).

[0166] Log Management System

[0167] In embodiments, the log management systems **904** shown in FIG. **9** can be configured provide information pertinent to a user's activities at the endpoint device and at the network level of operations based on logs generated by endpoint and network elements and reported through standard system information and event management protocols (e.g., SYSLOG) and formats such as the WebTrends Enhanced Log file Format (WELF) or the Common Event Format (CEF) used for network security applications.

Systems for Determining Calculus of Risk and Subject Reputation Scores

[0168] FIG. **10** is a block diagram illustrating an exemplary system for determining a calculus of risk. FIG. **10** is described with continued reference to the embodiments illustrated in FIGS. **4**, **5** and **8**. However, FIG. **10** is not limited to those embodiments.

[0169] Referring to FIG. **10**, the exemplary calculus of risk system **1000** includes a network endpoint assessment **1001** configured to generate a network security scan report **1025**, an endpoint collator **1002** to parse a plurality of received reports for categorization by address or geo-location, a normalizer **1003** for report consolidation, an object collator **1004** for categorization by package and component, an integrity processor **630** on a device **560**, for runtime system **1016**, application **1015** and user **1014** context, an endpoint trust agent **510**, a global object context generator **1005** for aggregation of context, an event processor **1006** for evaluation of context, a rules repository **1012** of object attributes configured to include at least constraints **1023**, a sample rate **1022**, a recurrence **1021**, a score **1020** and a weight **1019** for integrity assessments, an event correlator **1007**, an event correlation matrix **1013**, a threat classifier **1008**, a dashboard controller **1009**, and a remediation controller **848**.

[0170] Trust Supervisor

[0171] According to the exemplary embodiments of FIG. **8** and FIG. **10**, the trust supervisor **846** can be configured to receive infection profiles **832** from the network analyzers **830** and integrity profiles **420** from the system event correlator **410**. The trust supervisor **846** uses an event processor **1006**, an event correlator **1007**, a threat classifier **1008**, an event correlation matrix **1013** and a rules repository **1012** to correlate events associated to a device **560** for the classification and identification of threats based on the forensic confidence of leading indicators.

[0172] In an embodiment, the network endpoint assessment **1001** comprises performing a security scan of network endpoints for vulnerability, configuration, compliance, and patch management and use the results of these scans to generate a security assessment report **1026**. As shown in FIG. **10**, an endpoint collator **1002** is configured to receive the generated security assessment report **1026**. In embodiments depicted in FIG. **10**, at this point, the endpoint collator **1002** can then sort the security assessment report **1026** by endpoint address and/or geo-location to produce categorized reports **1027**.

[0173] A normalizer **1003** is configured to receive the categorized reports **1027** and then normalize the elements therein to produce normalized reports **1028**.

[0174] An object collator **1004** is configured to receive the normalized reports **1028** and then sort the elements therein by object package and component to produce temporal events **1029** for the global object context generator **1005**.

[0175] In certain exemplary embodiments, the global object context generator **1005** receives endpoint events **1018** that may include the local runtime object execution context from the integrity processor **630** on a device **1017**, and temporal events **1029** that may include endpoint security context from the object collator **1004**.

[0176] In exemplary embodiments, the event processor **1006** receives endpoint integrity profiles **420** from the global object context generator **1005**, retrieves associated endpoint rules **1031** from the rules repository **1012**, generates and sends endpoint alerts **1033** to the event correlator **1007**.

[0177] According to exemplary embodiments, the event correlator **1007** receives endpoint events **1033** from the event correlator **1007**, maps the alerts **1032** using the event correlation matrix **1013**, generates and sends endpoint warnings **1034** to the threat classifier **1008**.

[0178] In accordance with exemplary embodiments, the threat classifier **1008** may categorize threats, send status indications **1024** to the dashboard controller **1009** for real time visibility of endpoint integrity, and send action requests **1025** to the remediation controller **848**.

[0179] In certain exemplary embodiments, the endpoint collator **1002**, normalizer **1003** and object collator **1004** may be included in the trust broker **407** as described above with reference to FIG. **4**.

[0180] In certain exemplary embodiments, the global object context generator **1005** may be included in the system event correlator **410** described in FIG. **4**.

[0181] In certain exemplary embodiments, the event processor **1006**, event correlator **1007** and threat classifier **1008** may be included in the trust supervisor **846** as described in FIG. **8**.

[0182] FIG. **11** is a block diagram illustrating an exemplary system for determining a subject reputation. FIG. **11** is described with continued reference to the embodiments illustrated in FIGS. **4**, **5**, 7C, and **8-10**. However, FIG. **11** is not limited to those embodiments. For example, the system **1100** can be used to generate subject reputation scores based on a calculus of risk, such as the calculus of risk determined by system **1000** described above with reference to FIG. **10**.

[0183] Referring to FIG. **11**, the exemplary subject reputation system **1100** includes a user **1014** authenticated on a device **560** through an authentication process/ceremony **1115** with an authentication service **1103**, a service provider **1104** configured to receive a service request, a managed application **1105** that may be the target service, a reputation broker **1106**, a trust broker **407**, a log management system **904**, a role management system **902** and an identity management system **903**.

[0184] Unless specifically stated differently, a user is interchangeably used herein to identify a human user, a software agent, or a group of users and/or software agents. Besides a human user who needs use devices **560** and the attestation systems described herein, a software application or agent

sometimes needs to run applications, access services or social networks, conduct online transactions, review, update, or analyze security data, and process events, alerts and warnings. Accordingly, unless specifically stated, the term "user" as used herein does not necessarily pertain to a human being.

[0185] With continued reference to FIG. **11**, the exemplary subject reputation system **1100** also includes an inventory management system **901**, a reputation processor **1110**, a risk correlator **1111**, a risk correlation matrix **1113**, and a reputation score generator **1112**.

[0186] In an embodiment, the reputation processor **1110** is a component of the system event correlator **410** configured to receive subject events **1123** from the trust broker **407** and includes user alerts **1124** that are analogous to integrity profiles **420** of a user **1101**.

[0187] As shown in FIG. **11**, the risk correlator **1111** can be configured to receive subject alerts **1124** such as alerts for a user **1014** or a device **560**, and map the subject alerts **1124** to a cell in the risk correlation matrix **1113** grid analogous to the risk correlation matrix **721** in FIG. **7**C. The subject warnings **1126** (i.e., user **1014** or device **560** warnings) triggered can then be processed by the reputation score generator **1112** to determine the user's **1014** reputation score **1125**.

[0188] Subject Events

[0189] In embodiments, the subject events **1123** shown in FIG. **11** can be assertions about provisioned attributes, endpoint and network level activities associated with a subject, received as a response to a directed query from the respective management systems. The subject can be a user **1014**, a device **560**, a transaction, or an organization such as a company.

[0190] In certain exemplary embodiments, a device **560** sends a service request **1116** on behalf of a user **1014** to a service provider **1104** to access a managed application **1105**. The service provider **1104** sends a reputation query **1117** to the reputation broker **1106**, receives a reputation token **1118** that may include at least a reputation score for the user **1014** or device **560**, and enforces a reputation-based access control **1119** to permit or deny the service request **1116** to access the managed application **1105**.

[0191] Within the context of the subject reputation system **1100**, the trust broker **407** is configured to process received subject attributes (e.g., entitlements, memberships of users **1014**, roles for users **1014**, activity information), to generate and dispatch subject events to the reputation processor **1110**. The subject events represent assertions about the subject that may determine a level of security risk in a transaction (e.g., static and dynamic separation of duties, principle of least privilege, observed resource usage patterns, observed activities on the internal and external networks, etc.). In one embodiment, the queries **1121**, **1130**, **1122**, **1128** issued by the trust broker **407** are preconfigured, but can be customized by the administrator from a graphical user interface (GUI) or dashboard, such as the exemplary GUI described below with reference to FIGS. **14-18**. In embodiments, the management systems may include information systems hosted by social networking vendors such as FACEBOOK® operated by Facebook, Inc., Twitter operated by Twitter, Inc., and LinkedIn.

[0192] According to exemplary embodiments, the trust broker **407** receives a query **1120** for a reputation score for a subject (i.e., a user, device, transaction, service, or organization), sends a subject activity query **1121** to log management systems **904**, sends a subject attribute query to role management systems **902** and identity management systems **903**, sends a device attribute query to inventory management systems **1128**, generates and sends subject events **1123** to the reputation processor **1110**.

[0193] In the context of the subject reputation system **1100**, the inventory management system **901** shown in FIG. **9** can be configured to provide information pertinent to subjects that are devices **560**, including mobile devices **560**, mobile applications, enterprise desktops, servers, etc.

[0194] With continued reference to FIG. **11**, in an embodiment, associated device attributes include at least a device **560** geo-location, a device provisioned state, enabled/disabled device **560** functions, and an owner registration (i.e., a user **1014** registration or an organization registration).

[0195] In accordance with embodiments, the risk correlator **1111** is configured to receive subject alerts **1124**, use the risk correlation matrix **1113** to map the subject alerts **1124** to subject warnings **1126**, and invoke the reputation score generator **1112** to establish a subject reputation score **1125**, which can be included in the reputation token **1118** by the reputation broker **1106**.

[0196] In the exemplary embodiment of FIG. **11**, the subject alerts **1124** can be user **1014** alerts (i.e., user **1014** integrity profiles), device **560** alerts, or application alerts for an application executing on the device **560**. In certain exemplary embodiments, the reputation processor **1110** may be included in the system event correlator **410** described in FIG. **4**.

[0197] According to exemplary embodiments, the risk correlator **1111**, the risk correlation matrix **1113** and the reputation score generator **1112**, may be included in the trust supervisor **846** described in FIG. **8**.

Systems for Providing Network Flow Remediation and Mobile Security

[0198] FIG. **12** is a block diagram illustrating an exemplary system for network flow remediation. FIG. **12** is described with continued reference to the embodiment illustrated in FIG. **5**. However, FIG. **12** is not limited to that embodiment. The system **1200** can perform network flow remediation based on a calculus of risk.

[0199] Referring to FIG. **12**, the exemplary network flow remediation system **1200** may include an endpoint trust agent **1201** on a device **560** that may execute an application **1203**, a trust orchestrator **1205**, a plurality of collaboration services **1207** that may include malware analyzers, network endpoint assessment services, and reputation services, a network service **1230** that may include a network trust agent **1209** and an Open Flow security framework **1211**, an Open Flow controller **1214**, and an Open Flow enabled network element **1216** (for example, a switch or router).

[0200] In certain exemplary embodiments, the endpoint trust agent **1201** sends a dynamic context **1204** that may include the local runtime execution context of an application **1203** to the trust orchestrator **1205** that may perform a calculus of risk on a global security context, that may include endpoint assessment reports **1206** received from collaboration services **1207**, and sends a system warning **1208** (endpoint threat intelligence) as a subscription based reputation service to a network trust agent **1209** for network flow remediation.

[0201] In certain exemplary embodiments, the network trust agent **1209** sends messages **1210** to the OpenFlow security framework **1211** middleware to send directives **1213** to an OpenFlow controller **1214**, or send directives **1212** to an

OpenFlow controller **1214**, to notify by means of a protocol **1215** an OpenFlow enabled network element **1216** to apply access controls **1217** to block or divert traffic flows.

[0202] FIG. **13** is a block diagram illustrating an exemplary system for providing mobile security. FIG. **13** is described with continued reference to the embodiments illustrated in FIGS. **4-6**. However, FIG. **13** is not limited to those embodiments. System **1300** can provide mobile security by remediating mobile devices and wireless network flows based on a calculus of risk.

[0203] Referring to FIG. **13**, the exemplary mobile security system **1300** includes an endpoint trust agent **1301** on a mobile device **560** that may execute a mobile application **1303**, a trust orchestrator **1310**, a plurality of collaboration services **1312** that may include malware analyzers, network endpoint assessment services, and reputation services, a network service **1350** that may include a network trust agent **1315** and an network security framework **1318**, a network element **1320** (for example, a switch or router), a wireless access point **1322**, a mobile policy manager **1313** and a mobile device manager **1324**.

[0204] Endpoint Trust Agent

[0205] Referring to FIGS. **5**, **6** and **13**, in an embodiment, the endpoint trust agent **510** resides on a device **560**. The endpoint trust agent **510** can be configured to monitor all operations performed on the device **560** at runtime, including running applications and device functions (e.g., microphone, camera, keyboard, or display functions), and dispatches endpoint events **520** and security service requests **518** to the trust orchestrator **430**. The runtime monitor **620**, a functional component of the endpoint trust agent **510**, includes a system monitor **512**, a socket monitor **513**, and a process monitor **514** that receive raw events **611** from native machine instrumentation **511** using a notification mechanism (e.g., MICROSOFT™ WINDOWS® Management Instrumentation (WMI) or the Android Application Manager). In certain exemplary embodiments, the endpoint trust agent **520** may also receive and process messages from a mobile device manager **1324** or mobile policy manager **1313** to control device operations and/or settings. The endpoint trust agent **510** is risk and threat agnostic and merely generates events based on the evaluation of rulesets **631** and assessment of runtime behavior based on the threat correlation matrix **633**. The assessment of risk, and classification and identification of threats can be delegated to the trust orchestrator **430**.

[0206] In certain exemplary embodiments, the endpoint trust agent **1301** sends a dynamic context **1304** that may include the local runtime execution context of a mobile application **1303** to the trust orchestrator **1310** that may perform a calculus of risk on a global security context, that may include endpoint assessment reports **1311** received from collaboration services **1312**, and sends threat intelligence as a subscription based reputation service **1314** to a network trust agent **1315** for network flow remediation.

[0207] In certain exemplary embodiments, the network trust agent **1315** sends messages **1316** to the network security framework **1318** middleware to send policies **1319** to a wireless access point **1320**, or send policies **1317** to a wireless access point **1320**, to apply access controls **1321** to block or divert traffic flows.

[0208] In certain exemplary embodiments, the trust orchestrator **1310** sends messages **1307** to the mobile policy manager **1313** to send directives **1308** to the mobile device manager **1324** to set feature controls **1306** on the mobile device **560** or send directives **1305** to the endpoint trust agent **1301** for the integrity processor **630** and runtime monitor **620** of FIG. **6**.

[0209] In certain exemplary embodiments, the trust orchestrator **1310** is configured to send messages **1309** to the mobile device manager **1324** to set feature controls **1306** on the mobile device **560**.

Example User Interface Dashboards for an Administration Console

[0210] FIGS. **14-18** illustrate exemplary graphical user interfaces (GUIs) according to embodiments of the present disclosure. The GUIs depicted in FIGS. **14-18** are described with reference to the embodiments of FIGS. **1-13**. However, the GUIs are not limited to those example embodiments. FIGS. **14-18** illustrate an exemplary data center administration console interface comprising various dashboards for displaying data related to operational integrity, resource utilization, application integrity, and network activity, in accordance with embodiments of the invention.

[0211] The terms "console display," "display," "display screen," and "screen" are used interchangeably herein to refer broadly and inclusively to any type of display device or screen coupled to or integrated with a computing device for displaying content viewable by a user of the computing device, such as administrators for the systems describe herein or a user **1014** of a device **560**. In an embodiment, the device **560** is a mobile computing device **560**. Such a display screen can include, for example and without limitation, a touch-screen liquid crystal display (LCD). In embodiments of the invention, the GUIs of a mobile device **560** is viewed on a display. In other embodiments, the GUIs shown in FIGS. **14-18** are viewed on a display of a server (i.e., a server console), a desktop computer (i.e., a PC monitor), or a laptop display.

[0212] In the example GUIs shown in FIGS. **14-18**, the console interface and dashboards are rendered in a dedicated, native interface. In alternative embodiments, the console interface can be web based and rendered within a web browser. In other embodiments, the console interface and dashboards illustrated in FIGS. **14-18** can be displayed on server or workstation displays having a touch sensitive (i.e., touch screen) display. For ease of explanation, the operation of the console interface is discussed in the context of a computing device platform with an input device such as a mouse or pointing device (including a touch-screen), but is not intended to be limited thereto. Examples of such computing device platforms include, but are not limited to, OSX server and workstation operating systems (OSs) from Apple, Inc.; WINDOWS® server and workstation OSs from the MICROSOFT™ Corporation; UNIX-based OSs, and Linux OSs, such as, but not limited to, Linux from RedHat™ Inc.

[0213] In alternative embodiments, the GUIs of FIGS. **14-18** can be rendered on a display of a mobile computing device such as, but not limited to a personal digital assistant (PDA), an iPhone™, an iPod™ touch, or iPad™ tablet device, a device operating the Android operating system (OS) from Google Inc., a device running a MICROSOFT™ WINDOWS® Mobile or Phone OS, a device running a Symbian OS, a device running a PALM OS®, a BLACKBERRY® device running a Blackberry OS from Research In Motion ("RIM"), a smart phone, a hand held computer, a netbook computer, a palmtop computer, a laptop computer, an ultra-mobile PC, or another similar type of mobile device capable

of processing instructions and receiving and transmitting data to and from users and other computing devices.

[0214] It is to be understood that the console interface and dashboards illustrated in the exemplary embodiments of FIGS. **14-18** can be readily adapted to execute on a display of mobile device platforms and operating systems, a computer terminal, a display of a client device, a display console of a server, a display console of a monitoring device, a display of a target or subject device, or other display of a computing device. Thus, the exemplary GUIs illustrated in FIGS. **14-18** can be rendered on a display of a mobile device using an attestation application, within a web browser session, on a display console of an attestation server, or on a display of a client device running an attestation application.

[0215] Throughout FIGS. **14-18**, displays are shown with various icons, folders, panes, command regions, interfaces, windows, tabs, tiles, data entry fields, drop down menus, and buttons that are used to initiate action, invoke routines, monitor and display data related to operational integrity of, monitor resource utilization, or invoke other functionality. The initiated actions include, but are not limited to, viewing events, editing events, inputting calendar preferences, a backward scroll, a forward scroll, and other calendar view navigation inputs and gestures. For brevity, only the differences occurring within the figures, as compared to previous or subsequent ones of the figures, are described below.

[0216] In an embodiment, the display used to display the GUIs and dashboards shown in FIGS. **14-18** may be a computer display **2630** shown in FIG. **26**, and the console interface may be display interface **2602**. According to embodiments of the present invention, a user can interact with the console interface and dashboards using input devices such as, but not limited to, a touch screen, a pointing device, a stylus, a track ball, a touch pad, a mouse, a keyboard, a keypad, a joy stick, a voice activated control system, or other input devices used to provide interaction between a user and a GUI.

[0217] FIG. **14** depicts an exemplary GUI for a data center administration console **1400** including an operational integrity dashboard **1450**.

[0218] Referring to FIG. **14**, the exemplary data center administration console **1400** may visually display as a single pane an operational integrity dashboard or display window **1450** to provide a 'global view' of the data center inventory **1401** (i.e., a 'global view dashboard'). The display window **1450** can include information fields including the global view of the data center inventory **1401** in a hierarchical tree view of resources, a component level view of a resource **1402**, a resource name **1403**, a resource platform type **1404**, integrity metrics for a plurality of trust vectors that include at least the system configuration **1405**, resource utilization **1406**, application integrity **1407**, network activity **1408**, a remediation action **1409**, a remediation control **1410** that may include at least a restore, quarantine and divert users function, an action summary **1413**, a details pane **1411**, a status pane **1412**, and color coded runtime integrity indicators **1440**. The console **1400** can also graphically display risk indicators as integrity indicators **1440** and indications of impact analysis based on a confidence level of received integrity metrics for the trust vectors.

[0219] The information fields may be displayed and/or updated in real time or near real time. The color coded runtime integrity indicators **1440** for each displayed trust vector **1405**, **1406**, **1407** and **1408** may be animated and include audio-visual effects. For example, the integrity indicators **1440** can be animated with location changes, color changes, size changes, cross-fading, blinking, beeping, or vibration (i.e., when displayed on a mobile client device). In embodiments, some or all of the integrity indicators **1440** may be hyperlinked graphics with links to detailed dialog boxes, expanded views, or reports for a drill-down or detailed view of the corresponding trust vector.

[0220] Although the integrity dashboard **1450** is shown with specific information fields and labels in a particular arrangement, it is contemplated that other information fields and arrangements are possible. For example, additional trust vectors or a custom filter based perspective view may be displayed, or the dashboard may be embedded as a plug-in control and streamlined in a third party management console.

[0221] FIG. **15** depicts an exemplary GUI for a runtime operational integrity monitoring console **1500** including a system configuration dashboard **1550**.

[0222] Referring to FIG. **15**, the exemplary runtime operational integrity monitoring console **1500** may visually display a system configuration dashboard or display window **1550** in a single pane. The display window **1550** may include information fields including a severity **1501**, a warning or observed activity **1502**, a timestamp **1503**, an evaluation status **1504**, a recommended action **1505**, advanced details **1506** that may include a timestamp corresponding to the displayed threat details pane **1507**, source location, threat identifier and victim identifier, threat details pane **1507**, and machine history **1508** that may pertain to infection history.

[0223] The threat details pane **1507** may include a forensic evidence chain, a plurality of detected events that led to the infection diagnosis and threat identification.

[0224] Although the system configuration dashboard **1550** is shown with specific information fields and labels in a particular arrangement, it is contemplated that other information fields and arrangements are possible.

[0225] FIG. **16** depicts an exemplary GUI for a runtime operational integrity monitoring console **1600** including a resource utilization dashboard **1650**.

[0226] Referring to FIG. **16**, the exemplary runtime operational integrity monitoring console **1600** may visually display a resource utilization dashboard or display window **1650**. The display window **1650** may include information fields including a severity **1601**, a warning or observed activity **1602**, a timestamp **1603**, an evaluation status **1604**, a recommended action **1605**, advanced details **1606** that may include a timestamp corresponding to the displayed threat details pane **1607**, source location, threat (or malware) identifier and victim identifier, threat details pane **1607**, and machine history **1608** that may pertain to infection history.

[0227] The threat details pane **1607** may include a forensic evidence chain, a plurality of detected events that led to the infection diagnosis and threat identification.

[0228] Although the resource utilization dashboard **1650** is shown with specific information fields and labels in a particular arrangement, it is contemplated that other information fields and arrangements are possible.

[0229] FIG. **17** depicts an exemplary GUI for a runtime operational integrity monitoring console **1700** including an application integrity dashboard **1750**.

[0230] Referring to FIG. **17**, the exemplary runtime operational integrity monitoring console **1700** may visually display an application integrity dashboard or display window **1750**. The display window **1750** may include information fields including a severity **1701**, a warning or observed activity

1702, a timestamp **1703**, an evaluation status **1704**, a recommended action **1705**, advanced details **1706** that may include a timestamp corresponding to the displayed threat details pane **1707**, source location, threat (or malware) identifier and victim identifier, threat details pane **1707**, and machine history **1708** that may pertain to infection history.

[0231] The threat details pane **1707** may include a forensic evidence chain, a plurality of detected events that led to the infection diagnosis and threat identification.

[0232] Although the application integrity dashboard **1750** is shown with specific information fields and labels in a particular arrangement, it is contemplated that other information fields and arrangements are possible.

[0233] FIG. **18** depicts an exemplary GUI for runtime operational integrity monitoring console **1800** including a network activity dashboard **1850**.

[0234] As shown in FIG. **18**, an exemplary runtime operational integrity-monitoring console **1800** may visually display a network activity dashboard or display window **1850**. The display window **1850** may include information fields including a severity **1801**, a warning or observed activity **1802**, a timestamp **1803**, an evaluation status **1804**, a recommended action **1805**, advanced details **1806** that may include a timestamp corresponding to the displayed threat details pane **1807**, source location, threat (or malware) identifier and victim identifier, threat details pane **1807**, and machine history **1808** that may pertain to infection history.

[0235] The threat details pane **1807** may include a forensic evidence chain, a plurality of detected events that led to the infection diagnosis and threat identification.

[0236] Although the network activity dashboard **1850** is shown with specific information fields and labels in a particular arrangement, it is contemplated that other information fields and arrangements are possible.

Methods for Threat Identification and Remediation and Subject Reputation

[0237] FIGS. **19-22** are flowcharts illustrating exemplary methods for threat identification and remediation, providing a subject reputation service, and providing network flow level remediation.

[0238] The flowcharts depicted in FIGS. **19-22** are described with reference to the embodiments of FIGS. **1-8** and **11**. However, the methods **1900-2200** shown in FIGS. **1900-2200** are not limited to those example embodiments. The steps of the methods **1900-2200** shown in FIGS. **19-22** do not necessarily have to occur in the order described below. According to embodiments, some of the steps of the methods **1900-2200** are optional.

[0239] FIG. **19** is a flowchart illustrating an exemplary method for threat identification and remediation. Referring to FIG. **19**, the method **1900** may provide threat identification and remediation for an infected device **560** using a trust orchestrator **430**, an endpoint trust agent **510**, a network analyzer **830** and an endpoint assessment service **820**.

[0240] In step **1901**, raw events **611** from the native device and/or platform instrumentation **610** are received. In an embodiment, the endpoint runtime monitor **620** described with reference to FIG. **6** above receives the raw events **611**. After the raw events **611** are received, control is passed to step **1902**.

[0241] In step **1902**, image file and attributes are sent to a trust broker. According to an embodiment, this step is performed by the process monitor **514** described with reference to FIG. **5** above, that is included in the endpoint runtime monitor **620** described with reference to FIG. **6** above. In this embodiment, the process monitor **514** included in the endpoint runtime monitor **620** sends image file and attributes **518** to the trust broker **407** at the trust orchestrator **430** described with reference to FIG. **8** above so that specialized image analysis can be performed. After the image file and attributes **518** are sent, the method **1900** continues with step **1903**.

[0242] In step **1903**, the trust broker validates the image file based on received image attributes before passing control to step **1904**. In accordance with an embodiment, the validation in step **1903** can be performed by the trust broker **407** described with reference to FIG. **5** above.

[0243] In step **1904**, the trust broker (i.e., trust broker **407**) sends the received image file to a malware analyzer. In one embodiment, the malware analyzer is malware analyzer **540** described with reference to FIG. **5** above and the malware analyzer is configured to perform specialized static and dynamic image introspection of the received image file.

[0244] In step **1905**, a trust broker, such as, but not limited to, the trust broker **407**, generates and sends, based on a received diagnosis, an image profile to an endpoint process monitor. In an embodiment, this step comprises sending an image profile **519** to the endpoint process monitor **514** described above with reference to FIG. **5**. After the image profile is sent, control is passed to step **1906**.

[0245] In step **1906**, the endpoint runtime monitor **620** generates and sends integrity events, such as, but not limited to, integrity events **621**, to an integrity processor, such as, but not limited to, the integrity processor **630** described above with reference to FIG. **6**.

[0246] In step **1907**, the endpoint integrity processor **630** may process and map received events to alerts using rulesets **631**. In step **1908**, the endpoint integrity processor **630** may generate and send warnings **634** using an event correlation matrix **633** to the trust orchestrator **430** as endpoint events **520**.

[0247] In step **1909**, a system event correlator, such as, but not limited to, the system event correlator **410**, receives endpoint events **520** from the endpoint integrity processor **630**.

[0248] In step **1910**, the trust broker **407** receives network endpoint integrity measurement and verification reports **821** from an endpoint assessment service **820**.

[0249] In step **1911**, the system event correlator **410** receives temporal events **409** from the trust broker **407**.

[0250] In step **1912**, a system event correlator **410** may correlate the received endpoint and temporal events and generate an integrity profile **420** for the device **560** before passing control to step **1913**.

[0251] In step **1913**, the system event correlator **410** sends an integrity profile **420** of the device **560** to the trust supervisor **846**.

[0252] In step **1914**, the network activity correlator **831** sends infection profiles **831** to a trust supervisor, the trust supervisor **846**.

[0253] In step **1915**, the trust supervisor **846** may process the received integrity and infection profiles for classification of warnings based on forensic confidence for threat identification on the device **560**.

[0254] In step **1916**, the trust supervisor **846** sends to the remediation controller **848** actions **847** to perform on the infected device **560**. In step **1917**, the remediation controller **848** may process the received action request on the infected device **560** and send directives **849** based on configured

thresholds and triggers to system orchestration and policy enforcement point (or network security) services **860**.

[0255] FIG. **20** is a flowchart illustrating an exemplary method for providing a subject reputation service to a service provider. In the example embodiment of FIG. **20**, the subject is a user and the method **2000** provides a user reputation service. However, as discussed above with reference to FIGS. **9** and **11**, in alternative embodiments, the subject can also be a device, transaction, service, or an organization, such as a company.

[0256] In particular, FIG. **20** illustrates the steps by which a method **2000** provides a user reputation service for a service provider. In one embodiment, the service provider is the service provider **1104** described above with reference to FIG. **11** and the method **2000** can use a trust orchestrator, such as, but not limited to, the trust orchestrator **430** described above with reference to FIG. **8**.

[0257] According to embodiments, steps of the method **2000** can also be performed using an endpoint trust agent, a network analyzer, and a network analyzer, such as, but not limited to, the endpoint trust agent **510**, network analyzer **830**, and the endpoint assessment service **820** described above with reference to FIG. **8**.

[0258] In step **2001**, an endpoint runtime monitor, such as, but not limited to, the endpoint runtime monitor **620** described above with reference to FIG. **6**, receives raw events **611** from the native device and/or platform instrumentation **610**, detect and identify the user **1014** authenticated by the authentication service **1103** at the device **560**.

[0259] In step **2002**, the endpoint runtime monitor **620** receives user activity events from the native device and/or platform instrumentation **610**. After the user activity events have been received, control is passed to step **2003**.

[0260] In step **2003**, the endpoint runtime monitor **620** may generate and send integrity events **621** to the endpoint integrity processor **630**.

[0261] In step **2004**, the endpoint integrity processor **630** may process and map received events to alerts using rulesets **631**.

[0262] In step **2005**, the endpoint integrity processor **630** may generate and send warnings **634** using an event correlation matrix **633** to the trust orchestrator **430** as endpoint events **520**. After the warnings and event correlation matrix have been generated and sent, the method **2000** continues with step **2006**.

[0263] In step **2006**, the trust broker **407** may query and receive user and resource attributes **1121**, **1130**, **1122**, and **1128** from a plurality of collaboration services **904**, **903**, **902**, **901** and generate subject events **1123**. In step **2007**, the reputation processor **1110** may analyze received subject events **1123** and generate subject alerts **1124** (i.e., user alerts or integrity profiles).

[0264] In step **2008**, the risk correlator **1111** may correlate received subject alerts **1124**, such as user **1014** alerts, to generate user warnings **1126** using the risk correlation matrix **721**, and user reputation score **1125** using the reputation score generator **1112**.

[0265] In step **2009**, the trust supervisor **846** may process the received integrity and infection profiles for classification of warnings based on forensic confidence for threat identification of a user **1014** of the device **560**. The user **1014** may be associated with the device due to currently being logged into the device **560**, running an application on the device **560**, or by virtue of having account/user ID privileges to access resources such as files, data, applications, or web pages on the device **560**.

[0266] In step **2010**, the reputation broker **1106** receives a reputation query **1117** for the user **1014** of the device **560** from a service provider **1104**.

[0267] In step **2011**, the reputation broker **1106** sends a reputation token **1118** for the user **1014** of the device **560**. In an embodiment, the reputation token **1118** sent in this step includes at least a user reputation score **1125**. After the reputation token **1118** is sent, control is passed to step **2012**.

[0268] In step **2012**, the service provider **1104** applies a reputation-based access control **1119** in processing a service request **1116** received from the device **560** for the user **1014** to access a managed application **1105**. After the reputation-based access control has been applied, control is passed to step **2013**.

[0269] In step **2013**, the trust supervisor **846** sends to the remediation controller **848** actions **847** to perform on the network fabric for sessions of the user **1014** of the device **560**.

[0270] In step **2014**, the remediation controller **848** may process received action request for sessions of the user **1014** of the device **560** and send directives **849** based on configured thresholds and triggers to system orchestration and policy enforcement point (network security) services **860**.

[0271] FIG. **21** is a flowchart illustrating steps by which an attestation service for runtime operational integrity of systems executing on a computing platform using a network trust agent, endpoint trust agent and trust orchestration server can be provided. The steps of the method **2100** shown in FIG. **21** do not necessarily have to occur in the order described.

[0272] Referring to FIG. **21**, the method **2100** can provide network flow level remediation for an infected device **560** at a network element **1216** using a trust orchestrator **1205**, an endpoint trust agent **1201**, a network trust agent **1209** and collaboration services **1207**.

[0273] In step **2101**, the endpoint runtime monitor **620** at the endpoint trust agent **1201** on the device **560** sends a dynamic context **1204** that may include endpoint events **520** to the trust orchestrator **1205**.

[0274] In step **2102**, the trust orchestrator **430** may analyze received endpoint events **520** from the endpoint trust agent **1201** on the device **560** before passing control to step **2103**.

[0275] In step **2103**, the trust broker **407** receives and analyzes network endpoint assessments (or integrity measurement and verification reports) **821** from an endpoint assessment service (or collaboration services) **820** and generate temporal events **409**.

[0276] In step **2104**, the system event correlator **410** may correlate endpoint **520** and temporal **409** events and generate an integrity profile **420** for the device **560**.

[0277] In step **2105**, the trust supervisor **846** may generate and send to the remediation controller **848** flow remediation actions **847** to perform on the network fabric.

[0278] In step **2106**, the remediation controller **848** at the trust orchestrator **1205** sends to the network trust agent **1209** a system warning **1208** for the network device **560**. In step **2107**, the network trust agent **1209** may generate and send to the Open Flow security framework **1211** directives **1210** to formulate commands **1213** for the Open Flow controller **1214**.

[0279] In step **2108**, the OpenFlow controller **1214** sends rules **1215** to the Open Flow enabled network element

(switch) **1216** to divert or block traffic flows to/from the forewarned network device **560**.

[0280] In step **2109**, the OpenFlow enabled network element (switch) **1216** may enforce received access restrictions (controls) **1217** for the forewarned network device **560** before control is passed to step **2110**.

[0281] In step **2110**, the trust supervisor **846** may monitor and send reputation score updates **847** for the forewarned network device **560** to the remediation controller **848**. In step **2111**, the remediation controller **848** at the trust orchestrator **1205** sends system security posture status updates **1208** for the forewarned network device **560** to the network trust agent **1209**. After the reputation score updates are monitored and sent, the method **2100** proceeds to step **2112**.

[0282] In step **2112**, the network trust agent **1209** may generate and send to the Open Flow security framework **1211** directives **1210** to formulate commands **1213** for the Open Flow controller **1214** to restore normal flows to/from the forewarned network device **560**.

[0283] FIG. **22** is a flowchart illustrating a method in accordance with various exemplary embodiments.

[0284] Referring to FIG. **22**, the method **2200** can provide network flow level remediation for an infected mobile device **560** at a wireless access point **1320** using a trust orchestrator **1310**, an endpoint trust agent **1301**, a network trust agent **1315** and an endpoint assessment service **1312**.

[0285] In step **2201**, the endpoint runtime monitor **620** at the endpoint trust agent **1301** on the mobile device **560** sends a dynamic context **1304** that may include endpoint events **520** to the trust orchestrator **1310** before passing control to step **2202**.

[0286] In step **2202**, the trust orchestrator **430** may analyze received endpoint events **520** from the endpoint trust agent **1301** on the mobile device **560**.

[0287] In step **2203**, the trust broker **407** receives and analyzes network endpoint assessments (or integrity measurement and verification reports) **821** from an endpoint assessment service (or collaboration services) **820** and generate temporal events **409**. After the network endpoint assessments are analyzed and the temporal events are generated, the method **2200** proceeds to step **2204**.

[0288] In step **2204**, the system event correlator **410** may correlate endpoint **520** and temporal **409** events and generate an integrity profile **420** for the mobile device **560**.

[0289] In step **2205**, the trust supervisor **846** may generate and send to the remediation controller **848** flow remediation actions **847** to perform on the network fabric.

[0290] In step **2206**, the remediation controller **848** at the trust orchestrator **1310** sends to the network trust agent **1209** a system warning **1208** for the mobile device **560** before control is passed to step **2207**.

[0291] In step **2207**, the network trust agent **1209** generates and sends to the wireless access point **1320** policies **1317** to apply access controls **1321** for the mobile device **560**, at which point control is passed to step **2208**.

[0292] In step **2208**, the remediation controller **848** at the trust orchestrator **1310** sends to the mobile policy manager **1313** a system warning **1307** for the mobile device **560** or to the mobile device manager **1324** directives **1309** to set feature controls on the mobile device **560**.

[0293] In step **2209**, the mobile policy manager **1313** generate and send to the mobile device manager **1324** directives **1309** to formulate advisories and security settings for the registered user (service subscriber) and the mobile device **560** or set feature controls on the mobile device **560**.

[0294] In step **2210**, the reputation broker **1106** receives a reputation query **1117** for a mobile device **560** from a service provider **1104**.

[0295] In step **2211**, the reputation broker **1106** sends a reputation token **1118** for the device **560** that may include at least a security posture established by the trust supervisor **846** based on the received infection **832** and integrity **420** profiles for the device **560**.

[0296] In step **2212**, the service provider **1104** may apply a reputation-based access control **1119** in processing a service request **1116** received from the device **560** to access a managed application **1105**.

Entity Relationship Model and Hierarchical Subject Reputation

[0297] FIG. **23** is an entity relationship diagram illustrating exemplary relationships between entities and components used in a system for the calculus of a subject reputation score. For example, the entities and components depicted in the entity model **2300** can be used to generate reputation scores by the system **1100** described above with reference to FIG. **11**.

[0298] Referring to FIG. **23**, the exemplary reputation scoring system **2300** computes a reputation score for a user **1014** that is employed by, a member of, or otherwise associated with an organization **2303**. The user **1014** can be associated with the organization temporarily (i.e., as a contractor). The user **1014** uses one or more endpoint devices **560** to perform an online transaction **2304** with a service **2305** that is rendered by an application **2306** and managed by the organization **2303**, to participate in an activity **2307**. In embodiments, the activity **2307** is categorized as either social **2308** or professional **1409**.

[0299] According to embodiments, the organization **2303** can be, but is not limited to, a company, a government agency/division, a university or school, a hospital, a non-profit firm, or any other group that needs to secure systems, platforms, mobile computing devices, or other IT assets on behalf of its employees/members (i.e., users **1014** of devices **560**). The organization's **2303** IT assets can include, but are not limited to, servers, desktop computers, laptops, tablet computers, multi-function printers/scanners/fax machines, and network devices. The IT assets can be devices **560** owned or leased by the organization and directly controlled by the organization **2303**.

[0300] The IT assets can include devices **560** owned and managed by users **1014** (i.e., a user-owned mobile computing device in a BYOD environment) or the organization **2303** (i.e., a 'corporate' IT asset owned or leased by the organization **2303**). In an embodiment, the reputation scoring system **2300** can operate in a mixed environment of IT assets wherein the organization **2303** owns some devices **560**, leases some devices **560**, and users **1014** own other devices **560**. For example the organization **2303** may own enterprise servers and network devices (not shown), lease laptops, desktop computers/personal computers (PCs), and other endpoint devices **560** for users **1014** and simultaneously allow user **1014**-owned mobile computing devices **560** (i.e., smart phones, laptops, and tablets in a BYOD environment) to access the organization's **2303** domain via internal or external networks. The internal networks can be, but are not limited to, an intra-

net, a LAN, or a WAN. The external networks can be, but are not limited to, an extranet, a wireless data networks such as Wi-Fi, and the Internet.

[0301] The servers (not shown) in the reputation scoring system **2300** may be part of a server farm and can be, but are not limited to, application servers hosting applications **2306**, file servers, mail servers, database servers, proxy servers, and web servers. These servers can be enterprise servers owned by the organization **2303** or servers under a corporate lease. Alternatively, the servers can also be part of a remote, service-provider managed outsourced virtual data center (i.e., a cloud computing environment). The network devices can be networked storage devices, routers, switches, hubs, and firewalls. These network devices can be part of the organization's **2303** local area network (LAN) or wide area network (WAN).

[0302] FIG. **24** is a block diagram illustrating an exemplary hierarchical representation of a subject reputation score. The hierarchical representation **2400** can be used to report reputation scores generated by system **1100** described above with reference to FIG. **11**.

[0303] Referring to FIG. **24**, the exemplary hierarchical representation of a subject reputation score **2400** includes a reputation score **2401**, a transaction score **2409**, a user score **2407**, a service score **2408**, a social score **2402**, a professional score **2403**, a device score **2404**, an organization score **2405**, and an application score **2406**. In the exemplary embodiment of FIG. **24**, the organization score **2405** can be, for example a company score **2405**.

[0304] A reputation score may comprise one or more component scores (as an aggregation), where a component score is illustrated in FIG. **24** below an aggregate score (for example, a service score may be a component score of a transaction score). An aggregate reputation score may provide an enumerated list to annotate component scores included.

Application Event Monitoring Architecture

[0305] FIG. **25** is a block diagram illustrating an exemplary computing system architecture **2500** for monitoring application events for trusted execution with layered extensions to native machine instrumentation mechanisms. FIG. **25** is described with continued reference to the embodiments illustrated in FIGS. **4-6**. However, FIG. **25** is not limited to those embodiments.

[0306] Referring to FIG. **25**, the exemplary representation of the architecture **2500** instrumented for trust includes a device **560**, an endpoint trust agent **510**, native machine instrumentation **610**, extended trust instrumentation **2501**, a runtime monitor **620**, a system event correlator **410**, and a trust orchestrator **430**.

[0307] The runtime monitor **620** subscribes for, and receives, near real time asynchronous notifications of application events **2502** from the extended trust instrumentation **2501**. The application events **2502** may include registry, file system, network, storage, input (for example, keyboard), output (for example, screen display), memory (for example, peek or poke) and process operations (for example, thread creation), and usage of any system resource (for example, microphone or camera) by running applications on the target instrumented device **560**.

[0308] The extended trust instrumentation **2501** may be layered extensions to native machine instrumentation **610**, such as, for example, the WINDOWS® Management Instrumentation (WMI) on MICROSOFT™ WINDOWS® platforms.

[0309] As will be appreciated by persons skilled in the relevant art, WMI is a set of extensions to the MICROSOFT™ WINDOWS® Driver Model (WDM), which is a framework for device drivers that provides an operating system interface through which instrumented components (i.e., components of an instrumented platform) provide information and notification. WMI is a MICROSOFT™ implementation of the Distributed Management Task Force (DMTF) Web-Based Enterprise Management (WBEM) and the DMTF Common Information Model (CIM) standards. WMI is preinstalled on some MICROSOFT™ WINDOWS® Operating Systems (OSs) and allows scripting languages like Visual Basic Scripting Edition (VBScript) or Windows PowerShell to manage computing devices and platforms running a MICROSOFT™ WINDOWS® OS. Such management can be performed locally (i.e., on the server or platform being managed) or remotely from a computing device external to the managed platform/device.

[0310] In certain exemplary embodiments, the runtime monitor **620** may generate and send dynamic expressions or rules as application filters **2503** linked to one or more running instances of applications on the target instrumented device **560**.

[0311] The application events **2502** and application filters **2503** may be expressed using standards based schema definitions, such as for example the DMTF CIM specification. In a non-limiting embodiment, the CIM schema can be used to provide Trust-as-a-Service (TaaS).

[0312] In embodiments, the architecture **2500** can be used with APIs to subscribe for asynchronous application events such as, but not limited to, registry, file system, network, and process operations (e.g., Load Library, Remote Thread Attach, Peek/Poke Memory operations).

[0313] Embodiments of the architecture **2500** can include packaging of a TaaS endpoint comprising an endpoint trust sensor with OS updates, such as, but not limited to, MICROSOFT™ WINDOWS®, UNIX, Linux, and Apple OSX updates (i.e., OS and application upgrades and security patches for browsers, business productivity suites, device drivers, and other platform components). By using the architecture **2500**, an endpoint trust sensor can measure runtime operational integrity by evaluating risk based on 'actions' and leveraging the native machine instrumentation **610**.

[0314] In embodiments, the architecture **2500** also enables a network trust sensor to perform signature-less network activity correlation using a threat 'life cycle model' for clustering and classification of malware.

[0315] According to embodiments, the architecture **2500** enables trust orchestration for actionable intelligence based on real-time event correlation (i.e., a calculus of risk) by using an API collaboration bus for integration of security intelligence.

Example Computer System Implementation

[0316] Although exemplary embodiments have been described in terms of a computing device or instrumented platform, it is contemplated that it may be implemented in software on microprocessors/general purpose computers such as the computer system **2600** illustrated in FIG. **26**. In various embodiments, one or more of the functions of the various components may be implemented in software that

controls a computing device, such as computer system **2600**, which is described below with reference to FIG. **26**.

[0317] Aspects of the present invention shown in FIGS. **1-25**, or any part(s) or function(s) thereof, may be implemented using hardware, software modules, firmware, non-transitory computer readable media having instructions stored thereon, or a combination thereof and may be implemented in one or more computer systems or other processing systems.

[0318] FIG. **26** illustrates an example computer system **2600** in which embodiments of the present invention, or portions thereof, may be implemented as computer-readable code. For example, the network systems and architectures of FIGS. **1**, **4-6**, **8-13** and **25** can be implemented in computer system **2600** using hardware, software, firmware, non-transitory computer readable media having instructions stored thereon, or a combination thereof and may be implemented in one or more computer systems or other processing systems. Hardware, software, or any combination of such may embody any of the modules and components used to implement the architectures and systems **100**, **400**, **500**, **600**, **800**, **900**, **1000**, **1100**, **1200**, **1300** and **2500** of FIGS. **1**, **4-6**, **8-13** and **25**.

[0319] If programmable logic is used, such logic may execute on a commercially available processing platform or a special purpose device. One of ordinary skill in the art may appreciate that embodiments of the disclosed subject matter can be practiced with various computer system configurations, including multi-core multiprocessor systems, minicomputers, mainframe computers, computers linked or clustered with distributed functions, as well as pervasive or miniature computers that may be embedded into virtually any device.

[0320] For instance, at least one processor device and a memory may be used to implement the above-described embodiments. A processor device may be a single processor, a plurality of processors, or combinations thereof. Processor devices may have one or more processor "cores."

[0321] Various embodiments of the invention are described in terms of this example computer system **2600**. After reading this description, it will become apparent to a person skilled in the relevant art how to implement the invention using other computer systems and/or computer architectures. Although operations may be described as a sequential process, some of the operations may in fact be performed in parallel, concurrently, and/or in a distributed environment, and with program code stored locally or remotely for access by single or multiprocessor machines. In addition, in some embodiments the order of operations may be rearranged without departing from the spirit of the disclosed subject matter.

[0322] Processor device **2604** may be a special purpose or a general-purpose processor device. As will be appreciated by persons skilled in the relevant art, processor device **2604** may also be a single processor in a multi-core/multiprocessor system, such system operating alone, or in a cluster of computing devices operating in a cluster or server farm. Processor device **2604** is connected to a communication infrastructure **2606**, for example, a bus, message queue, network, or multi-core message-passing scheme.

[0323] The computer system **2600** also includes a main memory **2608**, for example, random access memory (RAM), and may also include a secondary memory **2610**. Secondary memory **2610** may include, for example, a hard disk drive **2612**, removable storage drive **2614**. Removable storage drive **2614** may comprise a floppy disk drive, a magnetic tape drive, an optical disk drive, a flash memory, or the like.

[0324] The removable storage drive **2614** reads from and/or writes to a removable storage unit **2618** in a well-known manner. Removable storage unit **2618** may comprise a floppy disk, magnetic tape, optical disk, etc. which is read by and written to by removable storage drive **2614**. As will be appreciated by persons skilled in the relevant art, removable storage unit **2618** includes a non-transitory computer usable storage medium having stored therein computer software and/or data.

[0325] In alternative implementations, secondary memory **2610** may include other similar means for allowing computer programs or other instructions to be loaded into computer system **2600**. Such means may include, for example, a removable storage unit **2622** and an interface **2620**. Examples of such means may include a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM, or PROM) and associated socket, and other removable storage units **2622** and interfaces **2620** which allow software and data to be transferred from the removable storage unit **2622** to computer system **2300**.

[0326] The computer system **2600** may also include a communications interface **2624**. Communications interface **2624** allows software and data to be transferred between computer system **2600** and external devices. Communications interface **2624** may include a modem, a network interface (such as an Ethernet card), a communications port, a PCMCIA slot and card, or the like. Software and data transferred via communications interface **2624** may be in the form of signals, which may be electronic, electromagnetic, optical, or other signals capable of being received by communications interface **2624**. These signals may be provided to communications interface **2324** via a communications path **2626**. Communications path **2626** carries signals and may be implemented using wire or cable, fiber optics, a phone line, a cellular phone link, an RF link or other communications channels.

[0327] The computer system **2600** may also include a computer display **2630** and a display interface **2602**. According to embodiments, the display used to display the GUIs and dashboards shown in FIGS. **14-18** and described above may be the computer display **2630**, and the console interface may be display interface **2602**.

[0328] In this document, the terms "computer program medium," "non-transitory computer readable medium," and "computer usable medium" are used to generally refer to media such as removable storage unit **2618**, removable storage unit **2622**, and a hard disk installed in hard disk drive **2612**. Signals carried over communications path **2626** can also embody the logic described herein. Computer program medium and computer usable medium can also refer to memories, such as main memory **2608** and secondary memory **2610**, which can be memory semiconductors (e.g., DRAMs, etc.). These computer program products are means for providing software to computer system **2600**.

[0329] Computer programs (also called computer control logic) are stored in main memory **2608** and/or secondary memory **2610**. Computer programs may also be received via communications interface **2624**. Such computer programs, when executed, enable computer system **2600** to implement the present invention as discussed herein. In particular, the computer programs, when executed, enable processor device **2604** to implement the processes of the present invention, such as the stages in the methods illustrated by the flowcharts

1900, **2000**, **2100** and **2200** of FIGS. **19-22**, discussed above. Accordingly, such computer programs represent controllers of the computer system **2600**. Where the invention is implemented using software, the software may be stored in a computer program product and loaded into computer system **2600** using removable storage drive **2614**, interface **2620**, and hard disk drive **2612**, or communications interface **2624**.

[0330] Embodiments of the invention also may be directed to computer program products comprising software stored on any computer useable medium. Such software, when executed in one or more data processing device, causes a data processing device(s) to operate as described herein. Embodiments of the invention employ any computer useable or readable medium. Examples of computer useable mediums include, but are not limited to, primary storage devices (e.g., any type of random access memory), secondary storage devices (e.g., hard drives, floppy disks, CD ROMS, ZIP disks, tapes, magnetic storage devices, and optical storage devices, MEMS, nanotechnological storage device, etc.), and communication mediums (e.g., wired and wireless communications networks, local area networks, wide area networks, intranets, etc.).

CONCLUSION

[0331] It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present invention as contemplated by the inventor(s), and thus, are not intended to limit the present invention and the appended claims in any way.

[0332] Embodiments of the present invention have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

[0333] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

[0334] Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range equivalents of the claims and without departing from the invention.

What is claimed is:

1. A method of providing an attestation service for providing runtime operational integrity of a system using a computing platform comprising a network trust agent, an endpoint trust agent, and a trust orchestration server, the method comprising:

receiving, at the trust orchestration server, a dynamic context including endpoint events;

analyzing, by the trust orchestration server, the received endpoint events;

receiving network endpoint assessments;

generating temporal events based at least in part on analyzing the network endpoint assessments;

correlating the received endpoint events and the generated temporal events; and

generating an integrity profile for the system.

2. The method of claim **1**, wherein the dynamic context is sent by the endpoint trust agent.

3. The method of claim **1**, wherein the network endpoint assessments are received from an endpoint assessment service.

4. The method of claim **3**, further comprising:

receiving integrity measurement and verification reports from the endpoint assessment service.

5. The method of claim **1**, wherein the network endpoint assessments are received from one or more collaboration services.

6. The method of claim **5**, further comprising:

receiving integrity measurement and verification reports from the one or more collaboration services.

7. The method of claim **1**, wherein the endpoint events and temporal events are received by a system event correlator from endpoint trust agents and a trust broker, respectively.

8. A method of providing flow level remediation to isolate infected or compromised systems and platforms from a computing network fabric using a network trust agent, an endpoint trust agent, and a trust orchestrator, the method comprising:

generating, by the endpoint trust agent, runtime system integrity alerts regarding execution anomalies and risks based on rulesets and a calculus of risk;

sending, by the endpoint trust agent, runtime system integrity warnings as endpoint events to the trust orchestrator;

generating, by the trust orchestrator, a system integrity profile for the endpoint based on analysis of the received endpoint events;

processing and correlating, by the trust orchestrator, one or more of:

a system integrity profile generated based on a calculus of risk,

a plurality of temporal events generated based on a normalization and collation of elements in endpoint assessment reports received from a plurality of collaboration services, and

a system infection profile received from a network analyzer;

sending, by the trust orchestrator to the network trust agent, system warnings based on endpoint execution state assessments; and

sending, by the network trust agent, messages or directives to OpenFlow security frameworks and/or controllers to apply flow controls based on the received execution state as a threat posture of a connection endpoint.

9. The method of claim **8**, wherein the integrity warnings comprise warnings regarding data events and content events; and wherein the endpoint events comprise data events and content events.

10. The method of claim **8**, wherein the remediation of an infected system is achieved without adversely reducing the total operating capacity or availability of the computing platform through on-demand instantiation and scaling of workloads.

11. The method of claim **10**, further comprising forwarding a notification conveying an infected or compromised state of a mobile computing device to a user associated with the mobile computing device, wherein the notification is one or more of:

an asynchronous push notification to an account associated with the user;

a short messaging service (SMS) text alert message forwarded to a phone number associated with the mobile computing device;

an email alert message forwarded to an email address associated with the user; and

a warning message displayed by a service on a display of the mobile computing device during initiation of a transaction with a service from the mobile computing device.

12. The method of claim **11**, wherein one or more features or capabilities of a mobile device are de-activated or activated as a remediation action.

13. The method of claim **12**, wherein the remediation action is based on the geo-location.

14. The method of claim **1**, further comprising:

generating, by a trust supervisor, one or more flow remediation actions to be performed on a network fabric;

receiving, at a remediation controller of the trust orchestrator, the flow remediation actions; and

sending, by the trust orchestrator, to the network trust agent, one or more system warnings pertaining to a network device associated with the one or more flow remediation actions.

15. The method of claim **14**, further comprising:

generating and sending, by the network trust agent, directives to formulate commands for an OpenFlow controller;

sending, by the OpenFlow controller, rules to an OpenFlow enabled network element or switch of the network fabric to divert or block traffic flow to/from the network device; and

enforcing, by the OpenFlow enabled network element or switch, received access restrictions or controls for the network device.

16. The method of claim **15**, further comprising:

monitoring and sending, by the trust supervisor, reputation score updates for the network device to the remediation controller;

sending, by the trust orchestrator, system security posture status updates for the network device to the network trust agent; and

generating and sending, by the network trust agent, to the OpenFlow security framework, directives to formulate commands for the OpenFlow controller to restore normal flows to/from the network device.

17. The method of claim **8**, further comprising:

determining, by the network analyzer, anomalies based on network activity correlation and malware detection; and

dispatching, by the trust orchestrator, the image files and attributes of an application for binary analysis, wherein the image files comprise compiled, intermediate, or interpreted code or scripts;

receiving a result of the binary analysis result identifying malicious activity as a set of threats identified based on the analysis; and

caching, by the trust broker, the results of the analysis indexed by a unique identifier for the image; and

generating and returning an image profile to the endpoint trust agent comprising assertions of malicious capabilities of the image to be monitored at runtime for subsequent generation of endpoint events by the endpoint trust agent.

18. The method of claim **17**, wherein the binary analysis is performed by one or more third party malware analyzers, and wherein the dispatch mechanism uses trigger filter expressions that specify a set of criteria that warrant initiation of image analysis such as frequency and volume of requests for analysis associated with the application image across deployed endpoint trust agents.

19. The method of claim **18**, wherein the third party malware analyzers are configured to perform static and dynamic analysis of application images based on policies specified by the trust broker.

20. A system for providing runtime operational integrity by determining execution anomalies and a threat posture of applications executing on computing platforms including mobile devices and client-server systems, the system comprising:

an endpoint trust agent including:

a process monitor configured to observe local execution context of the applications,

a socket monitor configured to observe network activities of the applications, and

a resource utilization module monitor configured to observe system and platform resources consumed by the applications; and

an application integrity module configured to assess operational integrities of the computing platforms based on a ruleset;

wherein native machine instrumentation for the computing platform is configured to:

represent event subscriptions, callbacks, notification mechanisms provided by an operating system (OS) on the computing platforms, and

generate raw events;

extended trust instrumentation;

a runtime monitor configured to:

subscribe to and receive near real time asynchronous notifications of application events for the applications from the extended trust instrumentation, and

generate and send dynamic expressions or rules as application filters linked to running instances of the applications;

a system event correlator configured to correlate system events of the computing platforms to determine a calculus of risk;

a trust orchestrator configured to orchestrate actionable intelligence based on the calculus of risk by integrating security intelligence about the computing platforms and the applications; and

an endpoint trust sensor configured to measure runtime operational integrity of the computing platforms by evaluating risk based on actions of an application executing on, or a user of, the computing platforms and receiving the raw events from the native machine instrumentation.

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